Report No. BDV25-977-31

Final Report

Best Practices for Construction and Repair of Bridge Approaches and Departures

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March 2018

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SI (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		Length		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		Volume		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		Temperature (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
Approximate Conversions from SI Units				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		Length		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		Temperature (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force and Pressure or Stress		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Best Practices for Construction and Repair of Bridge Approaches and Departures		5. Report Date March 2018 6. Performing Organization Code
7. Author(s) Qing Lu, Mingyang Li, Manjriker Gunaratne, Chunfu Xin, Md Mokaddesul Hoque, Manvitha Rajalingola		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil and Environmental Engineering College of Engineering University of South Florida, Tampa, FL 33620		10. Work Unit No. (TRAIS) 11. Contract or Grant No. BDV25-977-31
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee Street, MS 30, Tallahassee, FL 32399		13. Type of Report and Period Covered Final Report May 2016 – March 2018 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Florida Department of Transportation (FDOT) has experienced frequent distresses in bridge approach/departure asphalt pavements in its highway system. Commonly observed distresses include alligator cracking and rutting, which reduce roadway smoothness and safety. To minimize the pavement distress and improve ride quality, there is a need to determine the extent and root causes of the problem and to develop pavement rehabilitation strategies and guidelines. This research serves such purposes by carrying out three research tasks: (1) literature review and extent of the problem; (2) literature review and rehabilitation criteria; and (3) literature review and rehabilitation guidelines. This report summarizes the work and findings under all tasks. From the work under Task 1, it was found that in 2014-2015 on Florida Interstate highways, about 27% of bridges with asphalt pavements on their approaches/departures showed signs of cracking in their approach or departure asphalt pavements, and about 20% of the bridges have noticeable rutting in their approach or departure asphalt pavements. Bridges showing distresses in approach/departure asphalt pavements are mainly on I-75 and I-95. A variety of factors may cause excessive distresses in bridge approach/departure asphalt pavements, among which, inadequate asphalt layer thickness is one potential cause. The common maintenance and rehabilitation (M&R) techniques used by various states for bridge approach/departure asphalt pavements include crack sealing, patching, milling and overlay, and reconstruction. Most states do not have special M&R strategies and guidelines. From the work under Task 2, tentative criteria for rehabilitation of bridge approach/department pavements were recommended. From the work under Task 3, a step-by-step procedure was proposed for identifying and comparing feasible rehabilitation strategies for bridge approach/departure asphalt pavements. The recommended rehabilitation strategy selection procedure includes: (1) pavement condition survey and evaluation; (2) identification of pavement distress causes; (3) selection of rehabilitation techniques; (4) formation of rehabilitation strategies; (5) life-cycle cost analysis; and (6) selection of rehabilitation strategy.

17. Key Word Asphalt Pavement, Bridge Approach, Bridge Departure, Rehabilitation Criteria, Rehabilitation Guidelines, Pavement Design		18. Distribution Statement No restrictions.	
19. Security Classif. (of this report) Unclassified.	20. Security Classif. (of this page) Unclassified.	21. No. of Pages 152	22. Price

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EXECUTIVE SUMMARY

Frequent distresses have been observed on bridge approach/departure asphalt pavements in the Florida highway system. There is a need to determine the extent and causes of the problem and to develop pavement rehabilitation strategies and guidelines. This study was sponsored by the Florida Department of Transportation (FDOT) for such purposes. Research work was conducted under three tasks: (1) literature review and extent of the problem; (2) literature review and rehabilitation criteria; and (3) literature review and rehabilitation guidelines.

For the first task, the following work was carried out: a comprehensive literature review, communication with FDOT personnel for FDOT practices and inputs, a nationwide questionnaire survey, and analysis of condition survey data from Florida highway bridge approach/departure asphalt pavements. The literature review covered information related to bridge approach/departure asphalt pavements. A variety of literature sources were reviewed, including journal papers, technical reports and manuals from various state DOTs. Florida-specific bridge approach/departure asphalt pavement information was collected through document review and communication with FDOT personnel. In the nationwide questionnaire survey, eight questions covering various aspects of bridge approach/departure asphalt pavement were sent to relevant pavement, maintenance, and field engineers in all state DOTs, and responses from a total of 33 state DOTs were received. In the Florida highway bridge approach/departure asphalt pavement performance data analysis, pavement condition data were collected and analyzed for 1,155 Florida Interstate highway bridges with approach/departure asphalt pavements, using video log images and pavement condition survey data. These Interstate highway bridges are deemed a representative sample of the Florida highway bridges.

It was revealed that a variety of distresses may appear in the bridge approach/departure asphalt pavements, among which cracking, rutting, settlement issues, and raveling are most common across states. In Florida, cracking and rutting are commonly observed, and cracking tends to be more significant than rutting. About 27% of the over 1000 Florida Interstate highway bridges with approach/departure asphalt pavements showed signs of cracking, and about 20% of bridges have noticeable rutting in their approach/departure asphalt pavements. Bridges showing distresses in approach/departure asphalt pavements are mainly on I-75 and I-95. Literature review showed that the main factors causing excessive distresses in bridge approach/departure asphalt pavements may include embankment settlement, poor drainage features around bridge abutments, water intrusion in base and subbase layers, inadequate compaction of the subgrade and base layers, and stiffness difference among bridge deck, approach slab, and approach pavements. Thin asphalt layers were noticed on bridge approach/departure asphalt pavements in 9 out of the 33 states surveyed and on many FDOT Interstate highway bridges, particularly in Districts 2 and 5, and on I-75.

For the second task, a follow-up literature review and a follow-up nationwide questionnaire survey were conducted. The literature review covered information related to rehabilitation criteria for bridge approach/departure asphalt pavements, possible causes and countermeasures for typical pavement distresses, and rehabilitation practices for bridge approach/departure asphalt pavements. In the survey, a few state DOT agencies that had provided relevant feedback in the questionnaire survey completed in Task 1 were followed up with a specific focus on

rehabilitation criteria and rehabilitation techniques of bridge approach/departure asphalt pavements.

Based on the follow-up literature review and survey results, general rehabilitation practices for bridge approach/departure asphalt pavements include crack sealing, patching, milling and overlay, and reconstruction. In many states, pavement patches are placed at failed bridge approach pavement areas until the sections get resurfaced. Most states do not have special maintenance and rehabilitation (M&R) criteria and guidelines for bridge approach/departure asphalt pavements. A few criteria proposed by some states, however, were found in the literature, which are based on differential settlement, approach-relative gradient, smoothness, or bridge approach index. Based on the literature review findings, rating systems were recommended for evaluating the performance of bridge approach/departure asphalt pavements based on rut depth, International Roughness Index (IRI), and crack rating. Bridge approach/departure asphalt pavements that are rated below “fair” should be visually inspected and targeted for M&R.

For the third task, a step-by-step procedure was developed for condition evaluation and rehabilitation strategy selection for bridge approach/departure asphalt pavements. The procedure includes the following six steps:

(1) Conducting pavement condition survey and evaluation;
(2) Identifying pavement distress causes;
(3) Selecting rehabilitation techniques;
(4) Establishing rehabilitation strategies;
(5) Conducting life-cycle cost analysis;
(6) Selecting rehabilitation strategy.

Asphalt patching, milling and asphalt inlay, and reconstruction were identified to be commonly used in rehabilitation practices for inadequate bridge approach/departure asphalt pavements. In-place recycling, including full depth reclamation, is recommended as one rehabilitation technique for bridge approach/departure asphalt pavements. A modified structural deficiency approach is proposed for the milling and asphalt inlay design. The potential rehabilitation strategy alternatives for bridge approach/departure asphalt pavements are proposed to address various possible issues with the pavements. With respect to current FDOT rehabilitation practices for bridge approach/departure asphalt pavements, several changes are recommended.

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CHAPTER 1 INTRODUCTION

The Florida Department of Transportation (FDOT) has experienced frequent distresses on the Interstate highways where concrete bridge pavement transitions to asphalt pavement. Commonly observed distresses include alligator cracking and rutting, which reduce roadway smoothness and safety. The problem is particularly common along the outer travel lane that carries the majority of truck traffic. In some cases, it was observed that the thickness of asphalt concrete (AC) layer reduces significantly (e.g., as much as 6 in) as the pavement section gets closer to a bridge approach/departure slab, likely due to repeated resurfacing projects in which the contractors must transition the asphalt pavement to the bridge approach/departure slab. The inadequate AC layer thickness might be a potential cause of pavement distresses.

To minimize the pavement distress and improve ride quality, there is a need to determine the extent and causes of the problem, and to develop pavement rehabilitation strategies and guidelines. The rehabilitation solutions shall be practical and feasible to overcome obstacles such as temporary traffic control (TTC) restrictions, equipment accessibility, budget limitations, and to improve pavement structural number at minimum maintenance and rehabilitation (M&R) frequency.

The purpose of this research is to understand the extent and causes of frequent distresses in asphalt pavement transition areas adjacent to a bridge approach/departure slab and to develop appropriate pavement rehabilitation criteria and guidelines. The transition areas, as illustrated in Figure 1-1, may have a length of about 200 ft. Asphalt pavements in these areas are referred to as "**bridge approach/departure asphalt pavements**" or simply "**bridge approach pavements**" in this study. The pavements that are out of the transition areas are referred to as "**regular pavements**", as shown in Figure 1-1. For a regular pavement section that is adjacent to a bridge approach/departure asphalt pavement, it is also named as a "**control section**" in this study.

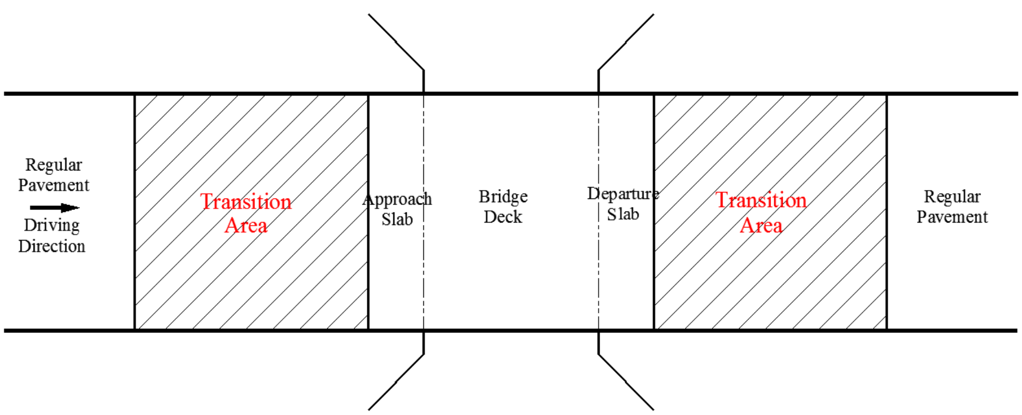


Figure 1-1 Schematic diagram of bridge approach/departure transition areas

The specific objectives of this research include:

- Determine the extent of the problem on Florida roadways. Identify the root causes of pavement distresses (e.g., fatigue cracking and rutting) and challenges associated with the repair of bridge approach pavements.

- Determine the selection criteria of rehabilitation strategies to alleviate pavement distress near bridge approaches and improve long term smoothness using the International Roughness Index (IRI) criteria.
- Develop rehabilitation guidelines based on an extensive literature review, assessment of critical issues, and construction industry engagement. Reasonably estimate the costs and benefits associated with developed guidelines.

To achieve the above objectives, four tasks were planned to be carried out

- Task 1: Literature Review and Extent of the Problem
- Task 2: Literature Review and Rehabilitation Criteria
- Task 3: Literature Review and Rehabilitation Guidelines
- Task 4: Prepare Draft Final Report and Final Report

The work performed for Tasks 1-3 consists of comprehensive literature review, nationwide questionnaire surveys, and collection, survey, and analysis of bridge approach/departure asphalt pavement data on Florida Interstate highways. This report summarizes the work and findings under the three tasks.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Making a smooth transition from a roadway pavement to a bridge deck has traditionally been somewhat of a challenge because the pavement side is relatively susceptible to settlement while the bridge deck is not. Pavements in the areas of bridge approaches may suffer accelerated levels of deterioration for a variety of reasons (Oregon DOT, 2011). Bridge approaches are defined as the section of pavement located immediately off the ends of a bridge, regardless of whether they are located on the approach side or leave side of the bridge (Oregon DOT, 2011). To distinguish the two sides of a bridge, the approach side and the leave side of a bridge may be denoted as bridge approach and departure, respectively. The problems with bridge approach/departure asphalt pavements are widespread and require investigations inclusive of the approach pavement system (White et al., 2007). Frequent pavement distresses on bridge approaches and departures will compromise ride quality, increase pavement M&R frequency and expenditure, and increase user cost such as delay due to traffic interruption by construction and added vehicle damage (Phares et al., 2011; Long et al., 1998).

This literature review was performed to gather information related to bridge approach/departure asphalt pavements, including pavement structures and materials used, common types of pavement distresses, major factors contributing to pavement distresses, and M&R techniques and strategies. While the objectives of this research focus on asphalt pavement transition sections adjacent to a bridge approach/departure slab, the review includes not only the pavement transition sections but also the pavements on bridge approach/departure slabs, due to the fact that they are sometimes included in the same definition of “bridge approach pavement” in the literature. Moreover, “bridge approach pavement” is also used to refer to a “bridge departure pavement” in some literature. In this review, therefore, the discussion on bridge approach pavements also applies to bridge departure pavements.

2.2 Pavement Structures and Materials on Bridge Approaches

Due to load restrictions and grade constraints on bridge structures, the design and rehabilitation techniques of new and existing bridge approaches require special consideration (Oregon DOT, 2011). A typical bridge approach pavement system, with one example shown in Figure 2-1 (Rufino et al., 2001), includes several different structures, such as approach slab, compacted embankment, drainage facility, and pavement layers. Approach slabs are typically used to provide a smooth vertical transition between the bridge approach pavement and the bridge. They are supported at the bridge end by the end bent and by the embankment at the roadway approach end (FDOT, 2012). To account for movement of the bridge, primarily due to temperature fluctuations, an expansion joint is always provided between the bridge deck and the approach slab. As shown in Figure 2-1, the bridge approach pavement not only includes pavement connector or possible asphalt overlay on the approach slab, but also includes a larger area of existing pavement. For example, in Oregon pavement design guide, bridge approach/departure asphalt pavement is analyzed for a distance of 200 ft from the ends of the bridge (Oregon DOT, 2011).

In Florida, bridge approach/departure pavements are typically constructed on compacted embankment or fill materials. When an approach slab is provided between the roadway pavement and the bridge deck, it is also paved, along with roadway pavements. In FDOT Design Standards (FDOT, 2012), a minimum asphalt overlay thickness of 1.75 in is required over the approach slab for flexible pavement approaches. Specifically, for FC-5, a 1.0 in structural course and a 0.75 in friction course are placed; for FC-9.5, a 0.75 in structural course and a 1.0 in friction course are placed; for FC-12.5, a 1.75 in friction course is placed.

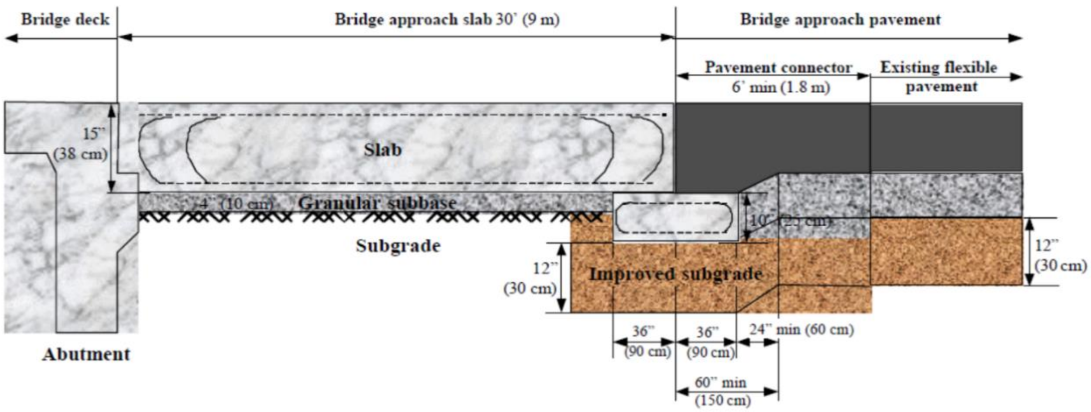


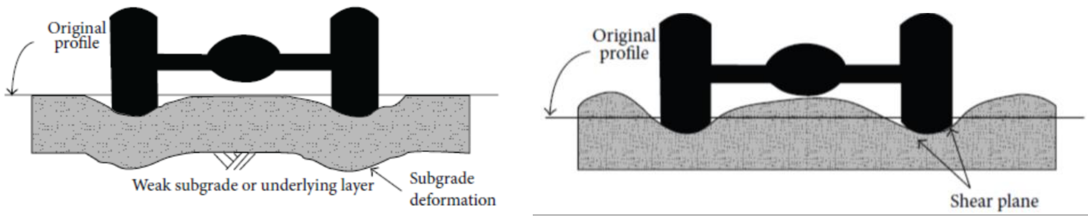
Figure 2-1 Elements of a typical bridge approach system (Rufino et al., 2001)

2.3 Common Types and Potential Causes of Pavement Distresses on Bridge Approaches

Literature review revealed various types of distresses in bridge approach/departure asphalt pavements, including differential settlement (bump), rutting, longitudinal cracking in wheel paths, transverse and map cracking, raveling, potholes, shoving, and bleeding.

The typical pavement distress at bridge approaches/departures is differential settlement among bridge deck, approach slab, and pavement. This is mainly because roadways and embankments are built on subgrade foundation and compacted fill materials that undergo load induced compression over time (White et al., 2005). The compression usually leads to pavement settlement that is much larger than the settlement of a bridge that is supported on deep foundations. The quality of embankment is critical to pavement performance. A poorly compacted embankment will result in excessive consolidation and settlement of the embankment material after the bridge approach is opened to traffic (Phares et al., 2011). More settlement is expected for higher embankments because of more compression within the embankment and higher loads applied to the foundation materials (Long et al., 1998). High differential settlements are also usually associated with water crossings because of the compressible, saturated soils located near water crossings (Allen, 1985; Hopkins, 1985; Stewart, 1985).

The post-compaction consolidation will not only lead to significant differential settlement, but may also cause rutting in asphalt pavements. As illustrated in Figure 2-2(a), consolidation rutting due to poor embankment quality can be identified in the field by the feature that there is no pavement uplift along the sides of a rut. On the contrary, as illustrated in Figure 2-2(b), instability rutting due to permanent shear deformation of the asphalt concrete layer can be identified by the occurrence of pavement uplift along the sides of a rut. Differential settlement and rutting can significantly impair ride quality and safety. In addition, differential settlement and significant stiffness differences among bridge deck, approach slab, and pavement can also accelerate the vibration effects of heavy trucks and increase traffic impact loads on pavements, particularly for pavements at bridge departures, thus resulting in shortened pavement service lives.



(a) Consolidation rutting (b) Instability rutting

Figure 2-2 Two common types of pavement rutting diseases (Harvey et al., 2001)

The longitudinal profile of pavement surfaces at bridge approaches/departures may affect vehicle speeds at these locations, which will impact the stress/strain responses of pavements, particularly for asphalt pavements since asphalt concrete is a temperature sensitive viscoelastic material. When a heavy truck reduces its speed on a bridge approach (i.e., uphill slope), it may cause more permanent deformation in the asphalt concrete material. Moreover, the bridge approach/departure areas are the typical location encountering the acceleration and deceleration effects of vehicles. Horizontal forces due to vehicle acceleration and deceleration, coupled with poor pavement interlayer bonding, may lead to problems such as shoving and delamination.

Erosion of backfill or embankment materials due to poor drainage will lead to void development under the approach slab, faulting of the approach slab, weakening of pavement base layers, and subsequent damages in asphalt pavements, including cracking, raveling, rutting, and moisture damage. For asphalt overlays on approach slabs, their performance is significantly affected by the quality and condition of the underlying slab since the slab virtually provides a rigid foundation support to the asphalt layer. Distresses in the approach slab, such as cracking, may be quickly reflected into the asphalt layer.

In summary, there are a variety of factors that may affect the performance of bridge approach/departure pavements, including those that are common to regular pavements, and those that are specific to bridge approach/departure asphalt pavements. Common to regular pavements, factors of traffic, climate, and pavement structure and materials will affect their performance. For bridge approach/departure pavements, in addition to the above factors, embankment that supports the pavement structure, drainage features around bridge abutments, elevation profiles of bridge approaches/departures, design of approach slabs, backfill materials under approach slabs, and expansion joint, water intrusion in base and subbase layer, significantly different stiffness values among bridge deck, approach slab, and approach pavement may also affect the bridge approach/departure pavement performance (White et al., 2005, Jayawickrama et al., 2005). Table 2-1 lists the general differences between features of bridge approach/departure pavements and control sections. The common types and potential causes of distresses in bridge approach/departure asphalt pavements are summarized in Table 2-2.

Review of technical reports and memorandums on the conditions of asphalt pavements on some Interstate highway bridge approaches in Florida showed that fatigue cracking and rutting were common at many bridge approaches (Parkash and Moseley, 2009). In some cases, there was a significant difference in the asphalt concrete layer thickness between a bridge approach/departure asphalt pavement and its control section. Typically, the asphalt concrete layer of a bridge approach/departure asphalt pavement was much thinner than that of a control section, and the difference may be as much as 66% of the asphalt layer thickness of control sections (Moseley, 2009, 2012, 2013; FDOT, 2009a, 2009b). The insufficient asphalt layer thickness is likely one reason for the excessive damages in bridge approach/departure asphalt pavements.

Table 2-1 General differences between features of bridge approach/departure pavements and regular pavements

Features	**Bridge Approach/Departure Pavement**	**Regular Pavement**
Structure and Materials	• Possible inadequate compaction practice • Thinner pavement surface layer • Incompatible stiffness effect • Possible joints failure problem	• Uniform compaction practice • Regular pavement surface layer • Uniform stiffness effect • No joints
Traffic Characteristics	• Relative low traffic speed • Possible acceleration/deceleration effect • High traffic impact load effect	• Regular traffic speed • Uniform vehicle speed • Normal traffic impact load effect
Environmental Condition	• Possible water intrusion • Differential settlement effect	• No water intrusion • Same compression and settlement

Table 2-2 Common types and potential causes of bridge approach/departure asphalt pavement distresses

Distress	**Description**	**Possible Causes**	**Picture**
Approach slab ramp	Differential settlement between bridge and approach slab	• Consolidation of foundation soil • Embankment vertical deformation • Poor compaction of filler	

Table 2-2 Common types and potential causes of bridge approach/departure asphalt pavement distresses (continued)

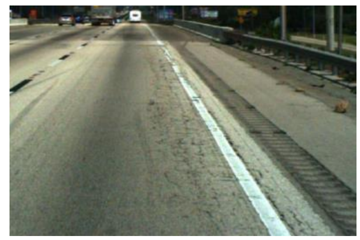
Distress	Description	Possible Causes	Picture
Differential settlement at pavement-bridge interface	Differential settlement at pavement-bridge interface	• Consolidation of foundation soil • Embankment vertical deformation • Poor compaction of filler	
Alligator (fatigue) cracking	Interconnected or interlaced cracks in the wheel path, forming a series of small polygons.	• Excessive loading • Weak surface, base, or subgrade (e.g., poor drainage, inadequate compaction) • Thin surface or base • Poor drainage	
Longitudinal cracking in wheel paths	Longitudinal cracks are predominantly parallel to pavement centerline.	• Aging effect of asphalt • Excessive loading • Impact factor • Weak surface, base • Thin surface or base • Poor drainage	
Transverse and map cracking	Transverse cracks are predominantly perpendicular to the pavement centerline.	• Aging effect of asphalt • Voids exist beneath the slab • Embankment compression	
Cracking at the expansion joint	Tensile-extrusion failure	• Expansion-contraction cycle • Impact load effect • Expansion joints failure	

Table 2-2 Common types and potential causes of bridge approach/departure asphalt pavement distresses (continued)

Distress	Description	Possible Causes	Picture
Rutting (mix rutting or subgrade rutting)	Surface depression in the wheel paths	• Poor compaction • Excessive loading • Weak asphalt mixtures • Insufficient design thickness • Moisture infiltration	
Shoving	Longitudinal displacement of a localized area of the pavement	• Braking or accelerating effects • Excessive moisture • Low air voids • Low vehicle speed • Excessive loading • Poor bond between pavement layers	
Bleeding or flushing	A film of asphalt binder on the pavement surface.	• Mixture problems • Improper construction practices • High temperature	
Raveling	Loss of bond between aggregate particles and the asphalt binder	• Aggregate segregation • Inadequate compaction • Poor mixture quality • Asphalt hardening due to aging	
Potholes	Depressions in the pavement surface that penetrate all the way through the HMA layer down to the base layer	• Thin surface layer • Moisture infiltration Excessive loading	

Table 2-2 Common types and potential causes of bridge approach/departure asphalt pavement distresses (continued)

Cracking at the transition from approach slab to pavement	Reflective cracking at joints	• Poor compaction • Impact load effect • Reflection cracks • Settlement	
Dip after approach slab	Differential settlement between approach slab and pavement	• Consolidation of foundation soil • Embankment vertical deformation • Poor compaction of filler	

Sources: (Lenke, 2006; White et al., 2005; Asphalt Institute, 2009; Michigan DOT, 2016; Nebraska DOR, 2002; Phares et al., 2011; Scullion, 2001)

2.4 M&R Techniques and Strategies

2.4.1 General Literature Review

The frequent distresses in bridge approach/departure asphalt pavements require frequent pavement M&R, which are more difficult to carry out than those on regular pavements due to factors such as restrictions of equipment accessibility and difficulties in TTC. For regular pavements, developing an appropriate rehabilitation strategy requires extensive investigation into the condition of the existing pavement structure, performance history, and laboratory testing of materials to establish suitability of existing and proposed materials for use in the rehabilitation design. The preferred rehabilitation strategy should consider cost-effectiveness, repair of the specific problems of an existing pavement, prevention of future problem, and meeting all existing constraints of the project (Texas DOT, 2016). Figure 2-3 shows a general rehabilitation technique selection process for regular flexible pavements (Illinois DOT, 2008). This selection process should also be followed in the rehabilitation of bridge approach/departure asphalt pavements.

The literature contains several studies on the criteria for triggering remedial countermeasures for bridge approach/departure pavements. Wahls suggested that a **differential settlement** of 0.5 in is likely to produce a "bump at the end of the bridge" that will require maintenance (Wahls, 1990). Long et al. (1998) developed a rating system for bridge approach settlement, as shown in Table 2-3. They found that bridge departures exhibit somewhat poorer behavior than bridge approaches. The difference may be related to impact loading, which is caused by vehicles riding off the bridge structure and landing on the subsided exit slab. Significant rider discomfort usually is felt with a settlement of greater than or equal to 2 in. However, it was found that most approach distress and rider discomfort were manifested in an approach-relative gradient. The **approach-relative gradient** is defined as the differential settlement divided by the length over which the settlement occurs. This led to the development of the following criteria for the remediation of differential movement at the approach embankment-bridge interface. The criterion for initiating remedial measures is an approach-relative gradient of greater than or equal to 1/200 (Long et al., 1998). The approach-relative gradient can be estimated easily from an elevation survey of the approach that extends at least 200 ft from the bridge ends. With this criterion, most of approach pavements with slopes greater than 1/200 in Iowa, as shown in Figure 2-4, were identified for M&R based on ride quality information determined from independent field tests (White et al., 2007).

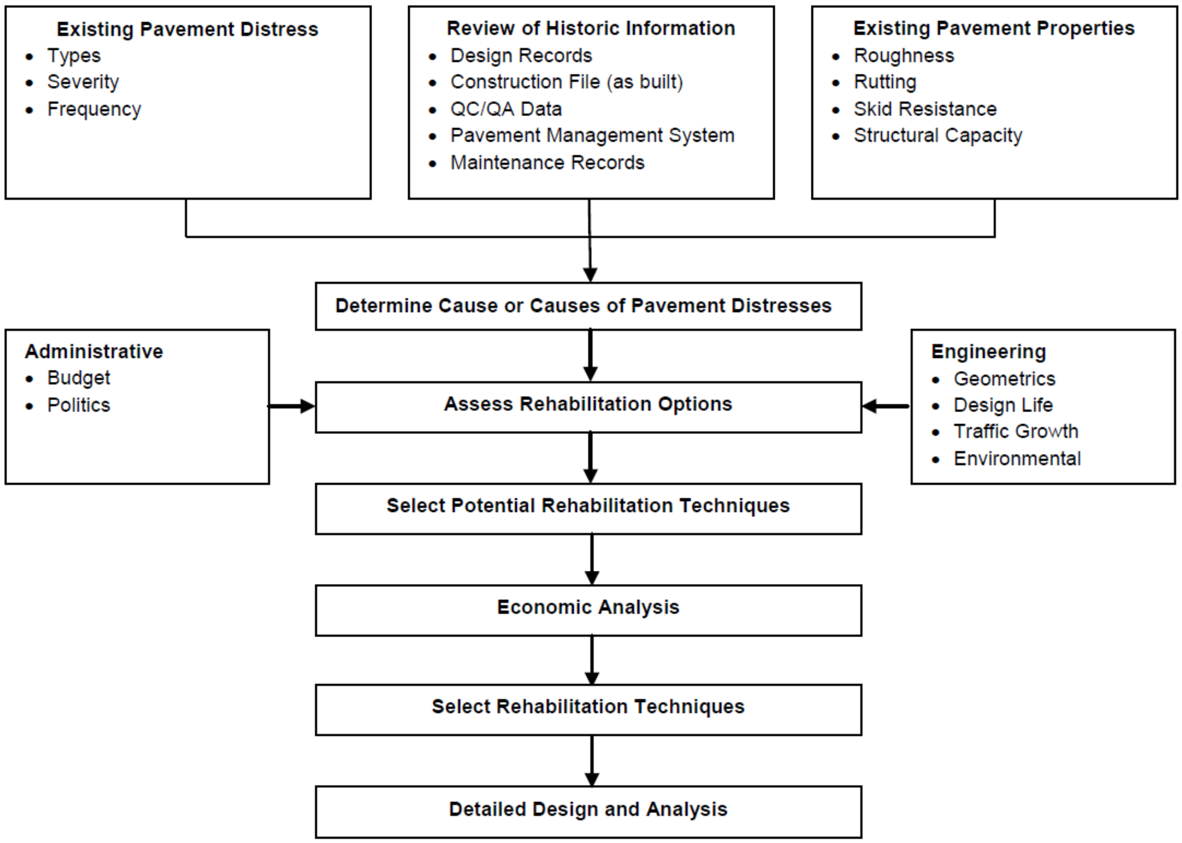


Figure 2-3 Rehabilitation technique selection process for regular pavements (Illinois DOT, 2008)

Table 2-3 Subjective rating system for differential settlement (Long et al., 1998)

Qualitative Visual Rating	Approach/Bridge Interface Description	Differential Settlement
0	No bump	0 in
1	Slight bump	< 1 in
2	Moderate bump	< 2 in
3	Significant bump	< 3 in
4	Large bump	> 3 in

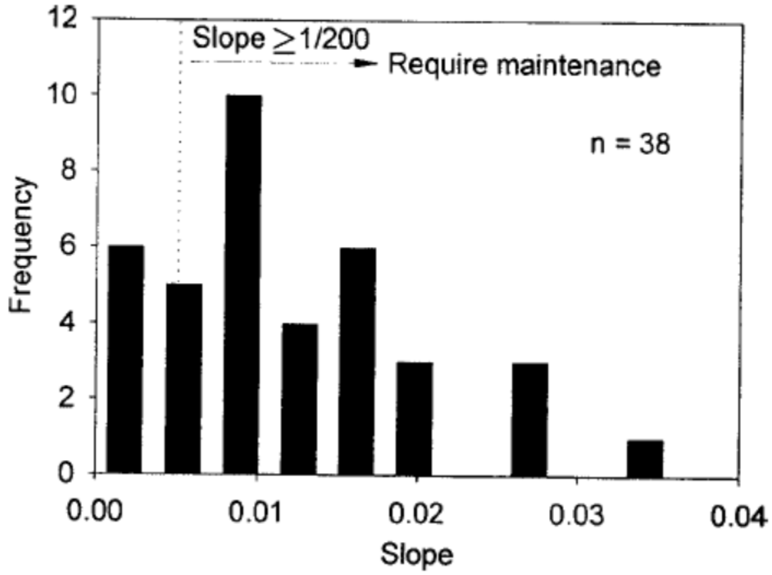


Figure 2-4 Histogram of bridge approach relative gradient in Iowa (White et al., 2007)

Another method for documenting the ride quality of approach pavements is through evaluating the IRI data (Sayers, 1995). Smoothness is the single most important indicator of performance from the standpoint of the traveling public since it affects driver safety, fuel efficiency, ride quality, and vehicle wear and tear (FHWA, 2006).

Das et al. concluded that an IRI value of 250 in/mi or less at bridge approaches indicates a very good ride quality. On the other hand, if the IRI value reaches 630 in/mi, the approach leading to a bridge is considered to have a very poor ride quality (Das et al., 1999).

White et al. investigated the IRI values at the transition locations for 23 bridge approach/departure pavements, with typical results shown in Figure 2-5 and Figure 2-6 (White et al., 2005). They found that the IRI on bridge approach/departure pavements increased with pavement age, and was greater on the outer lane than that on the inner lanes. Minimum smoothness values were observed at transition between bridge-approach slab and approach slab-roadway. Average IRI values on bridge approach/departure pavements were over two times higher than those on the adjacent roadways. They also found that minimum smoothness value can be used as the criterion for initiating remediation. A new indicator, named as **Bridge Approach Index (BI)**, was defined in their study to evaluate the bridge approach performance. This indicator was defined graphically as the area between the current bridge approach elevation profile and the original elevation profile (as shown in Figure 2-7) divided by the bridge approach length. They used both the maximum IRI and BI values to develop pavement condition rating criteria, as shown in Figure 2-8 (White et al., 2005).

Lenke stated that bridge approach pavements should be visually inspected once the IRI rating of the bridge approach/departure pavement is greater than 380 in/mi (Lenke, 2006).

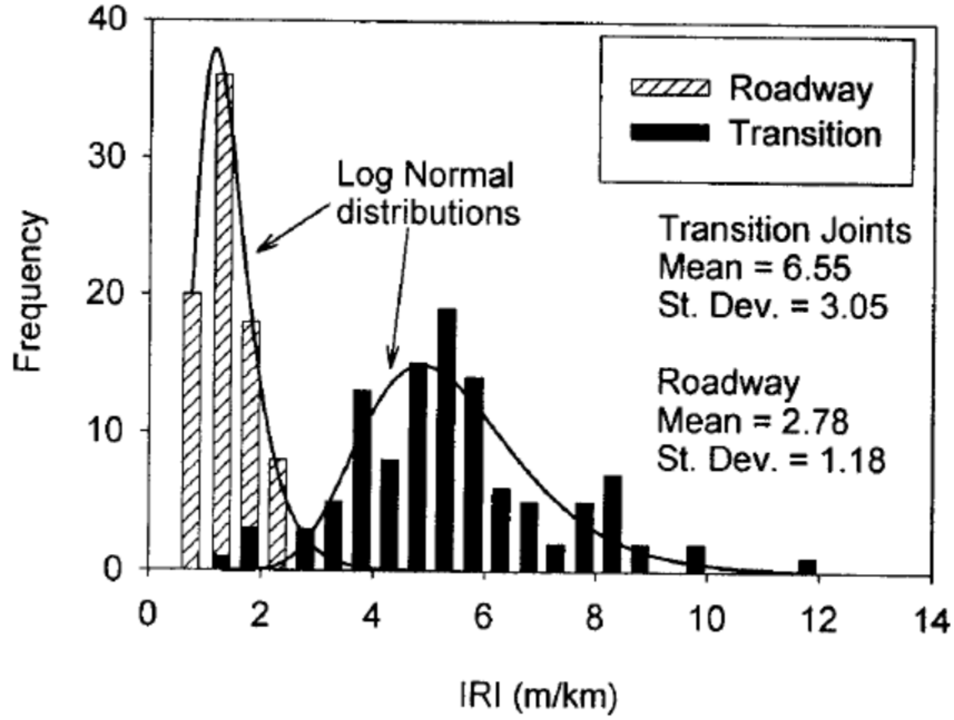


Figure 2-5 Distributions of IRI on roadway and bridge approaches (White et al., 2007)

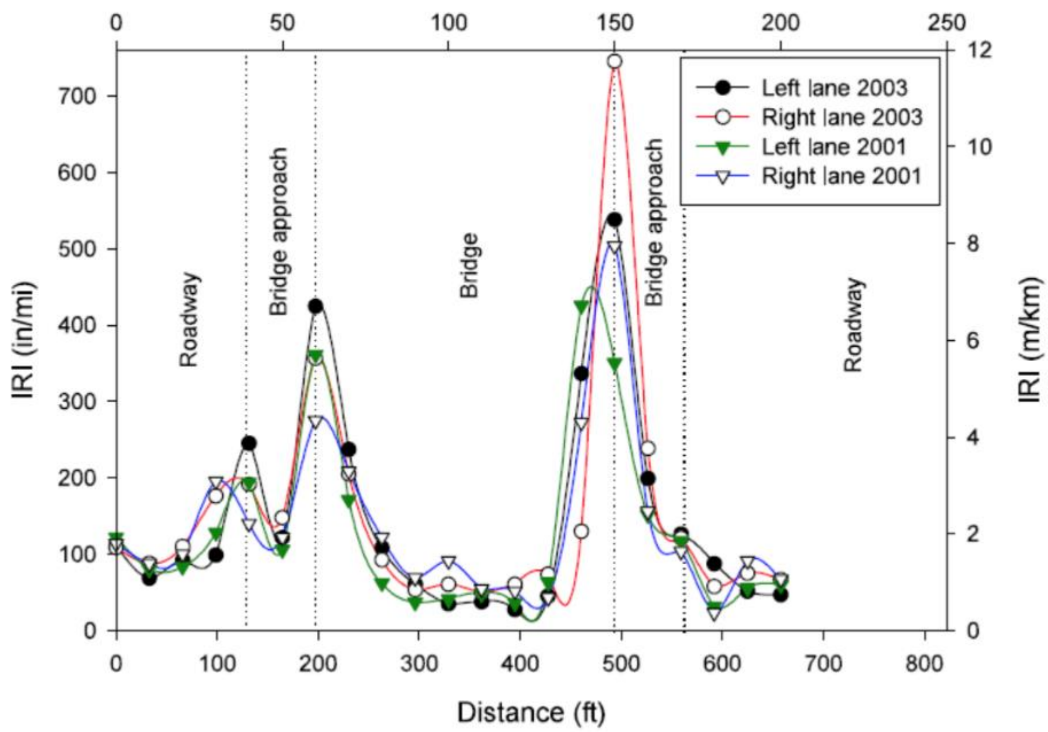


Figure 2-6 Typical IRI for bridge approach profile (White et al., 2007)

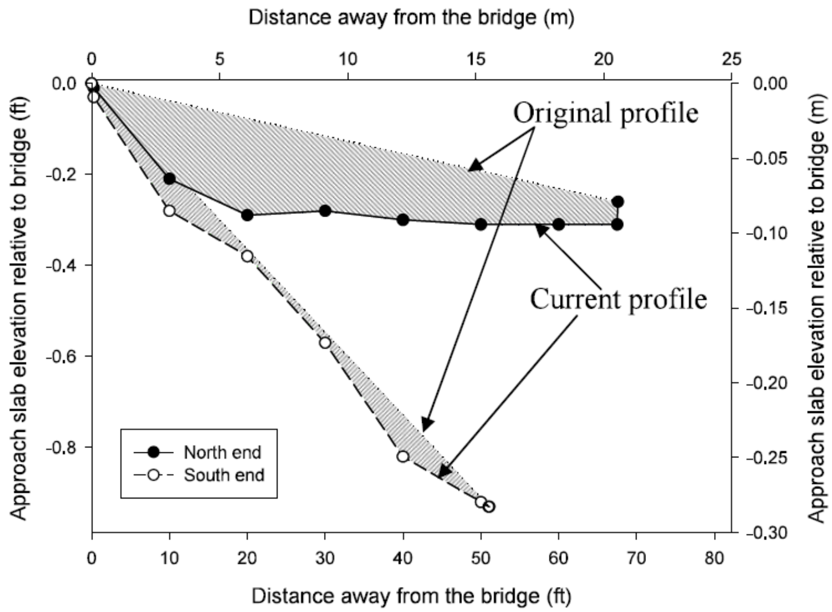


Figure 2-7 Illustrations of the definition of bridge approach index (BI) (White et al., 2005)

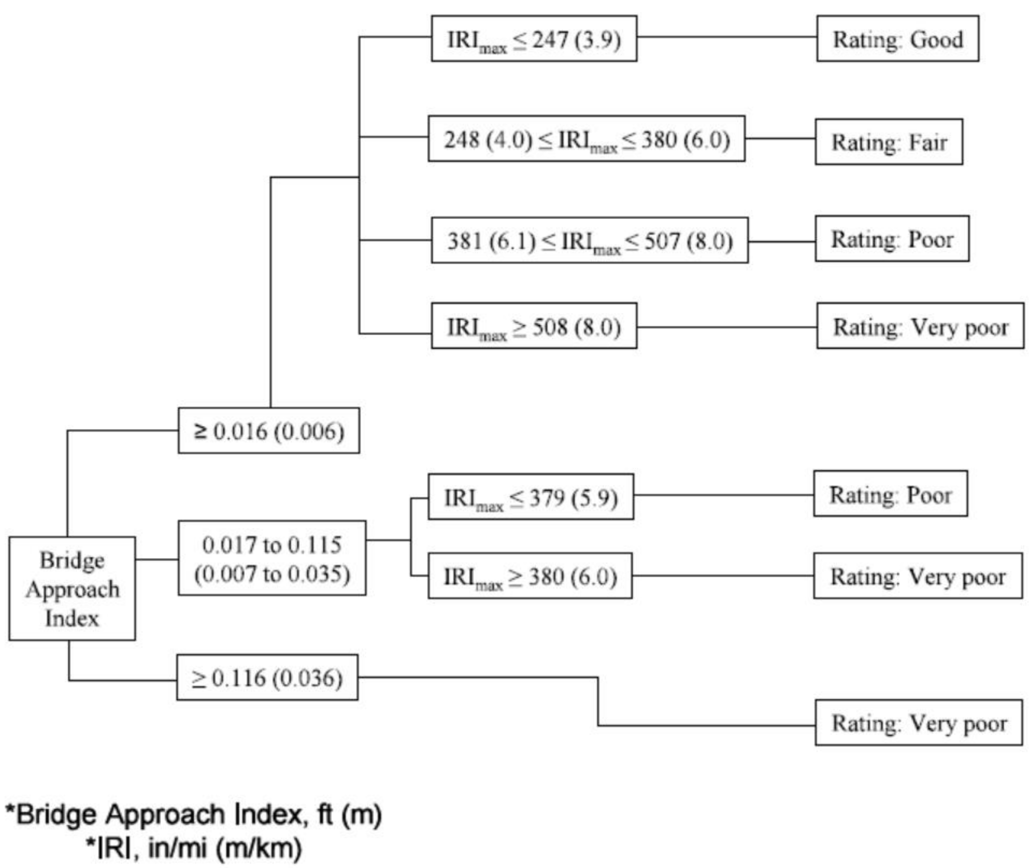


Figure 2-8 One rating system of bridge approach performance (White et al., 2005)

The rehabilitation criteria found in the literature for bridge approach pavements are summarized in Table 2-4.

Table 2-4 Rehabilitation criteria for bridge approach pavements

Performance Indicators	Rehabilitation Criteria
Differential Settlement (S)	S ≥ 0.5 in (Wahls, 1990)
Approach-relative Gradient (Δ)	Δ ≥ 1/100 (Long et al., 1998)
Bridge Approach Index (BI)	BI ≥ 0.017 ft (White et al., 2005)
International Roughness Index (IRI)	IRI_{max} ≥ 380 in/mi (White et al., 2005)

In addition, the specific criteria about selecting rehabilitation methods for bridge approach pavements in the state of Montana are summarized as follows. There are three options for bridge approach pavement treatment: (1) 30-year bridge end treatment: 30-year design life would be used for reconstruction of bridge approach pavement; (2) Minor bridge end treatment: if the roadway within 100 ft of the bridge ends is showing increased signs of distress compared with the overall project roadway condition, mill an additional 2.4 in (of existing plant mix and/or base course) for the standard 200 ft transition and replace with new plant mix; (3) Applying no additional treatment at the bridge end: if the roadway within 100 ft of the bridge ends is not showing increased signs of distress compared with the overall project roadway condition, no additional treatment is necessary beyond the standard milled transition (Montana DOT, 2015).

The general practice about bridge approach pavement milling and resurfacing design in South Dakota is shown in Figure 2-9 (Gill L Hedman, personal communication, May 31, 2017).

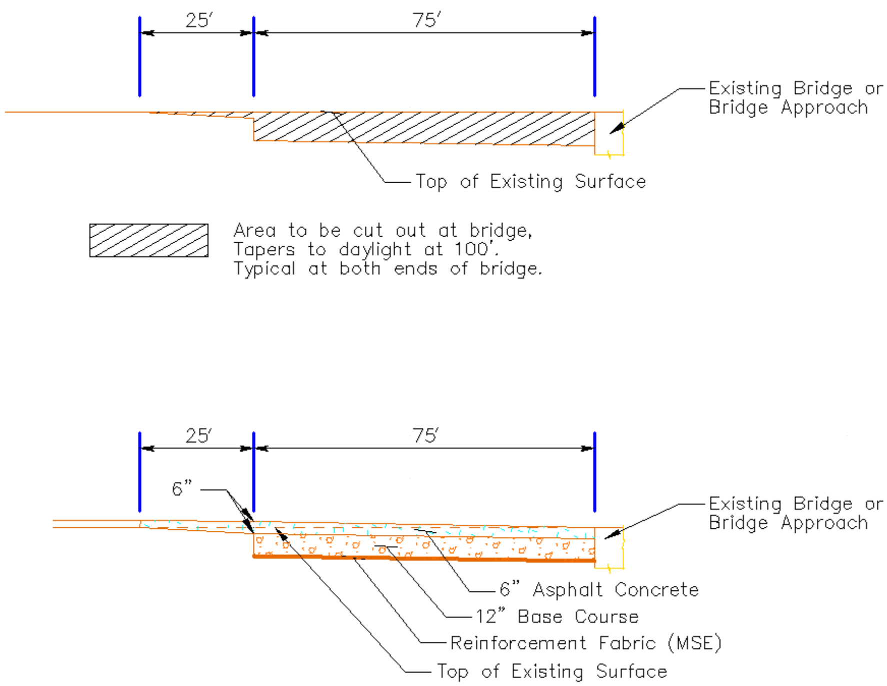


Figure 2-9 Bridge approach pavement replacement design in South Dakota

Once it is decided to initiate the M&R activity, the first step in selecting the optimum M&R technique for a bridge approach/departure pavement is to identify the causes of existing pavement distresses. The selection process for M&R technique is often straightforward once the causes are identified (Scullion, 2001). The common M&R techniques for bridge approach pavements are listed in Table 2-5.

Table 2-5 Typical M&R techniques for bridge approach pavements

M&R Option	Description	Distress Addressed	Picture
Crack Seals	Rubberized asphalt materials are used to fill cracks that develop in pavement.	• Longitudinal cracks • Transverse cracks • Reflection cracks (For low severity)	
Spray Injection Patching	The spray injection process can mix aggregate and asphalt binder together.	• Fatigue cracking • Transverse cracking • Rutting • Potholes	
HMA Patching	Patches are a common method of treating an area of localized distress.	• Raveling • Rutting • Cracking • Potholes • Settlement	
Asphalt Wedge	Asphalt wedge (ranging in length from 1 ft to 10 ft) can be placed to smooth the vertical transition.	• Bump • Rutting • Cracking • Potholes • Settlement • Patching	
HMA Overlay	Laying hot mix asphalt layer over an existing pavement structure.	• Bump • Rutting • Cracking • Potholes • Settlement • Patching	

Sources: (Dupont and Allen, 2002; Johanns and Craig, 2002; Maryland DOT, 2002)

Many agencies used asphalt resurfacing over an existing bridge approach as an inexpensive method for solving the bridge approach problems. However, if the causes of pavement distresses come from the sub-surface layer, the pavement distresses will not be addressed validly. If the distresses identified in a pavement are related to structural deficiencies, the pavement section is most likely not a candidate for preventive maintenance, and should instead be scheduled for rehabilitation or reconstruction (Jayawickrama et al., 2005). To determine the major causes of observed pavement distresses, detailed condition survey and analysis are needed.

2.4.2 FDOT Repair Practices

A review of FDOT pavement survey reports and rehabilitation recommendations memorandums showed that over the last decade, there have been a few pavement rehabilitation projects in which bridge approach pavements received extra repair effort than regular pavements, and typically excessively thin asphalt layers were discovered in these bridge approach/departure sections (Parkash and Moseley, 2009; Moseley, 2009, 2012, 2013; FDOT, 2009a, 2009b).

The FDOT District materials and maintenance offices were contacted for their current repair practices for bridge approach/departure asphalt pavements. From received responses it is found that the general repair practices for bridge approach/departure asphalt pavements are patching, milling and resurfacing, compaction grouting and chemical grouting, and reconstruction.

- In Districts 1 & 7, in most cases the same milling was conducted on the approach slabs, bridge approach pavements, and mainline pavements. If approach slab settlement and noted pavement distress are caused by weak subsurface condition, pressure grouting and chemical grouting are conducted below the approach slab and in the approach roadway area. For example, in the project numbered as FPN 425032-1-62-01 in Okeechobee County (completed in 2015), standard compaction grouting of the approach roadway area and chemical grouting below the approach slab were recommended when it was found that a combination of ground movement and surface water movement from the bridge/roadway caused the issues (Bennett and Jean, 2015).
- In District 2, based on several pavement distress exploration reports (FIN 423432-1-52-01, FIN 428803-1-52-01, and FIN 428804-1-52-01), it was found that there had been a number of bridges on I-75 in District 2 whose approach/departure pavements exhibited excessive distresses (i.e., rutting, fatigue cracking, and raveling). The recommended repair strategy for the outer (truck) lane was typically milling 2.75 in existing pavement, and resurfacing with 2 in Type SP SUPERPAVE Structural asphalt layer and 0.75 in FC-5 friction course. However, when the thickness of asphalt layer is inadequate (4-6 in), milling into the base layer to allow for a thick asphalt layer (one example is at least 7 in) resurfacing was recommended, because the pavement structure outside of the area adjacent to the approach and departure slabs is 9 or more inches of asphalt (Moseley, 2009). In addition, reconstruction of the bridge approach/departure asphalt pavements with thicker asphalt layer was also recommended as needed, particularly for sections with inadequate asphalt thickness (Moseley, 2009, 2012, 2013).
- In District 3, it was noted that generally pavements in the approach/departure areas performed similarly to those on regular pavements. Current repair practice is typically milling 2.75 in existing pavement, and resurfacing with 2 in Type SP SUPERPAVE structural asphalt layer and 0.75 in FC-5 friction course.

- In Districts 4 & 6, due to increase of heavy traffic, the asphalt surface layer thickness of regular pavements would increase during the resurfacing process. However, asphalt surface layer thickness on bridge approach pavement does not change with time. When the structural capacity of bridge approach pavement is not enough, the rehabilitation practice would be full depth reconstruction.
- In District 5, there have been two projects in which corrective actions were taken on bridge approaches that had exceeded the milling recommendations on the rest of the roadways. The two projects are FPN 419437-1-52-01 on I-75 in Marion County (completed in 2009) and FPN 423567-1-52-01 on I-95 in Brevard County (completed in 2011). The repair strategy was to mill deeper to remove all of the asphalt at the approaches and even enter the base material. Such a strategy avoided the more expensive reconstruction recommendations. Generally, District 5 considers a deeper rehabilitation of bridge approaches than regular pavement based on asphalt layer thickness, the severity of cracking on or near the approach, and the level of patching required to maintain the approach.

2.5 Summary of Literature Review

Bridge approach/departure pavement is a complex system that consists of more structural components than control sections. In addition to the distresses common on control sections (e.g., such as cracking and rutting), excessive surface deformation (e.g., dip, ramp, differential settlement) is also frequently observed due to embankment deformation or foundation soil consolidation. On Florida Interstate highways, typical distresses in bridge approach/departure asphalt pavements are fatigue cracking and rutting. The typical causes for cracking and rutting may include weak base layer or subgrade layer (high moisture content), structural deficiency (thin layer), poor joints, and steep side slope. The specific causes for each bridge approach/departure asphalt pavement distress can be identified after conducting one or more detailed condition surveys, including visual inspection, asphalt pavement core testing, falling weight deflectometer (FWD) testing, ground penetrating radar (GPR) survey, or standard penetration test (SPT).

The literature contains several studies on the types and causes of asphalt pavement distresses on bridge approaches/departures. A variety of contributing factors have been analyzed, but there is little documentation or discussion on the asphalt layer thickness and its influence on pavement performance. The technical reports and memorandums from FDOT, however, clearly showed the presence of very thin asphalt layer adjacent to a bridge approach/departure slab and excessive distresses in the corresponding pavement sections.

Criteria used to determine M&R needs for bridge approach/departure pavements (including approach/departure slabs) have included differential settlement, approach-relative gradient, smoothness (in terms of IRI), and bridge approach index.

M&R techniques for bridge approach/departure asphalt pavements include those for control sections (e.g, crack sealing, patching, and milling and overlay), and some unique ones such as asphalt wedging. It is noted in the literature that identification of the main causes of pavement distresses is important because pavement distress may result from structural deficiencies that have to be addressed at deep layers. In FDOT, the typical repair practice for bridge approach/departure asphalt pavements is milling 2.75 in existing pavement, and resurfacing with 2 in structural asphalt layer and 0.75 in friction course. For bridge approaches/departures with excessive pavement distresses and thin asphalt layers, deep milling into the base layer before resurfacing was practiced in some districts. Reconstructing the approach/departure asphalt pavements based on pavement design was also recommended as needed.

CHAPTER 3 QUESTIONNAIRE SURVEYS

3.1 Introduction

As a supplement to the literature review, a nationwide questionnaire survey was conducted to collect information on the extent, causes, and repair practices of damaged or deficient bridge approach/departure asphalt pavements in various states across the nation. Based on responses received, follow-up surveys were conducted on rehabilitation techniques for structurally deficient asphalt pavements with roadway vertical alignment constraint. Meanwhile, a questionnaire survey of FDOT districts was also conducted to collect current bridge approach pavement rehabilitation practices in Florida.

3.2 Nationwide Questionnaire Survey

A questionnaire was designed and distributed to relevant state DOT personnel across the nation. There are eight questions in the survey which are divided into three parts based on the theme of information they demand. Part A of the questionnaire consists of four questions dealing with the type and extent of pavement distress at bridge approaches/departures and information on any difference in pavement thickness at problematic locations. Part B contains a single question that inquires the causes of asphalt damage at problematic locations. Part C includes three questions related to M&R strategies practiced by respondents at problematic locations.

The respondents who participated in the survey include bridge engineers, pavement management engineers, materials and tests engineers, field engineers, state maintenance managers, and other personnel in state DOTs. A total of 33 responses from 50 state DOTs were received, as listed in Table 3-1 along with their abbreviations.

Table 3-1 State DOTs responded in the survey

State	DOT Abbr.	State	DOT Abbr.	State	DOT Abbr.
Alabama	ALDOT	Kentucky	KYTC	Ohio	ODOT
Alaska	DOT&PF	Louisiana	LADOT	Oregon	ODOT
Arizona	AZDOT	Maryland	MDOT	Pennsylvania	Penn DOT
California	Caltrans	Michigan	MiDOT	Rhode Island	RIDOT
Colorado	CDOT	Minnesota	MnDOT	South Carolina	SCDOT
Florida	FDOT	Mississippi	MDOT	South Dakota	SDDOT
Georgia	GDOT	Missouri	MODOT	Tennessee	TDOT
Hawaii	HDOT	Montana	MDT	Utah	UDOT
Idaho	ITD	Nebraska	NDOR	Virginia	VDOT
Illinois	IDOT	Nevada	NDOT	Washington	WSDOT
Iowa	Iowa DOT	New Mexico	NMDOT	Wisconsin	WisDOT

The detailed responses from all the participants of the survey are shown in Appendix A. Below are summaries and discussions of the information collected in the survey.

3.2.1 Extent of Asphalt Pavement Damage at Bridge Approaches and Departures

Part A of the survey is designed to collect information on the extent of pavement damage found in each respondent state by posing the following four questions:

1. *Do you notice more distress or damage of the asphalt pavement adjacent to bridge approach/departure slabs than on regular asphalt pavement sections on highways in your state?*
2. *Roughly what percentage of asphalt pavements adjacent to bridge approach/departure slabs have showed more distresses than regular asphalt pavement sections on highways in your state?*
3. *Can you please describe the types of asphalt pavement distress you have observed adjacent to bridge approach and departure slabs?*
4. *In the areas where you noticed distress or damage on the asphalt pavement, was there a significant difference in the asphalt thickness adjacent to the bridge approaches or departures compared to the rest of the roadway?*

The responses received from 33 states for each of the above question are summarized hereafter. For Question 1, 18 out of 33 respondents answered in the affirmative, as shown in Figure 3-1.

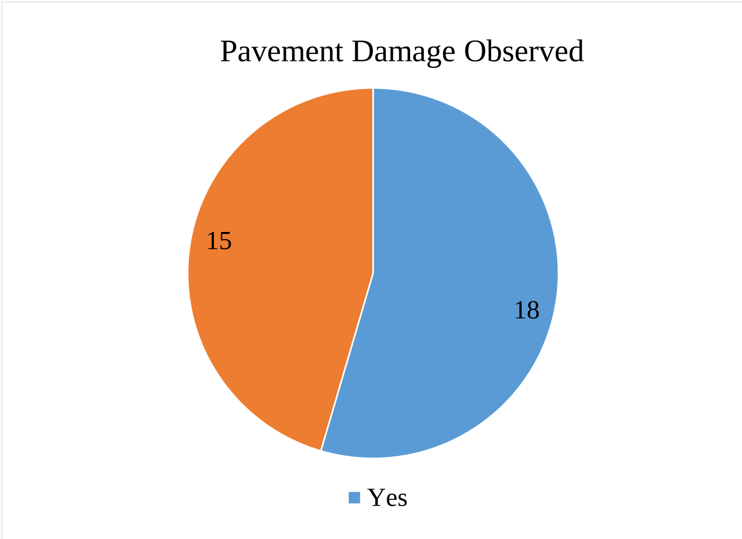


Figure 3-1 Is more damage observed in asphalt pavements near bridges

For Question 2, only three states said that they observed over 50% of pavement damage at the problematic locations. 20 states responded that they typically see less than 25% of pavement damage at such locations. Figure 3-2 describes the responses to Question 2 in more details.

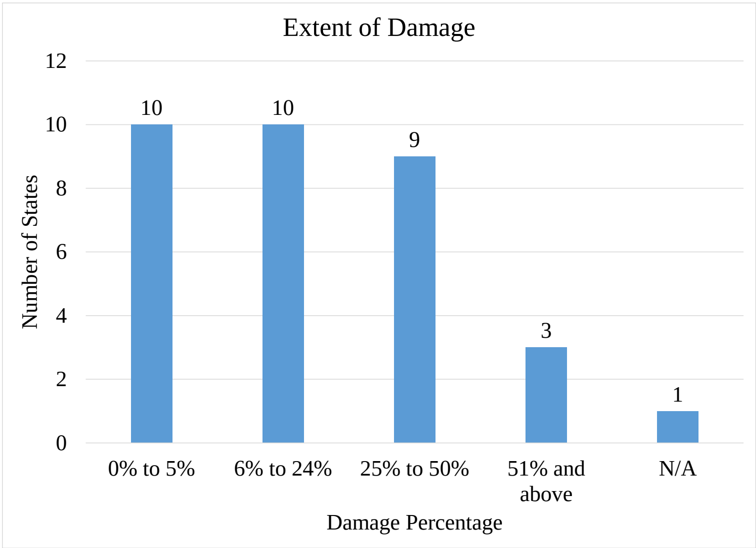


Figure 3-2 To what extent is the pavement damaged

In response to Question 3, thirteen types of pavement distresses were reported, including shoving, stripping, bumps, deformations, poor drainage, bleeding, cracks, settlement issues, poor compaction, potholes, pop-outs, rutting and raveling, which are generally consistent with the findings in the literature review. Figure 3-3 presents the frequencies of the distresses reported.

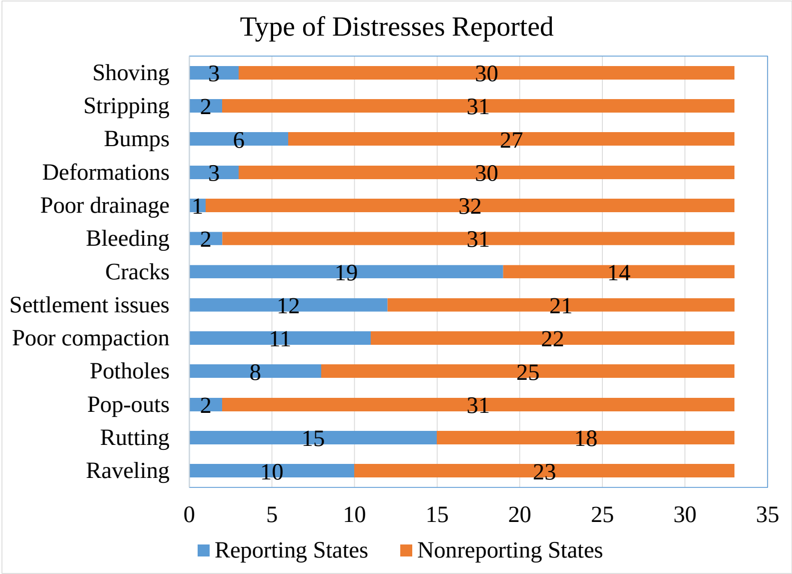


Figure 3-3 Frequencies of reported distresses

Question 4 inquiries about the existence of changes in the asphalt layer thickness on bridge approaches and departures. About 9 out of the 33 responding states indicated that they had noticed a reduced thickness of the asphalt layer adjacent to the bridge approach slabs or bridge ends, as shown in Figure 3-4. These states included Alabama, Arizona, Florida, Georgia, Illinois, Louisiana, Montana, South Carolina, and Washington. The primary reason stated in the responses is that during resurfacing projects, the asphalt layer would be feathered down to tie in at the bridge end slab to maintain the longitudinal grade.

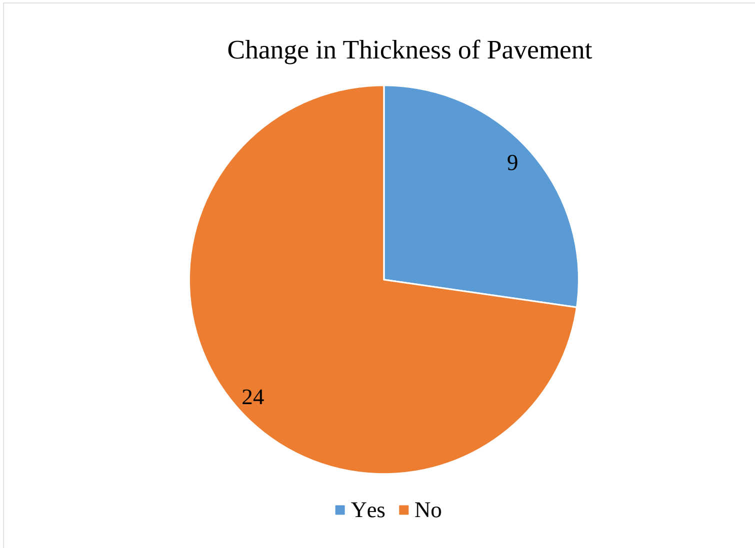


Figure 3-4 Changes in asphalt layer thickness on bridge approaches and departures

3.2.2 Causes of Asphalt Pavement Damage on Bridge Approaches and Departures

Part B is aimed at gathering information on the causes of pavement damage on bridge approaches and departures. There is only one question (Question 5) in this section.

5. *What do you think are the potential causes of asphalt pavement distress adjacent to bridge approach/departure slabs in your state?*

The causes of pavement distresses at problematic locations as reported by the respondents are summarized below.

In Arizona they noticed that the distresses in asphalt pavement transitions are due to material change from rigid to flexible. For most of the states (Penn DOT, TDOT, VDOT, NMDOT, MI DOT, ITD, FDOT, CDOT, LADOT, Maryland DOT), damages near bridge approach and departures are caused by inadequate compaction that eventually leads to a weak base. Insufficient drainage and settlement issues are also reported by many states. Alaska DOT has noticed damages near problematic bridges are due to plows and studded tires. Caltrans answered that most of the cracks appear due to inadequate drainage behind the abutments and not enough usage of non-erodible base. Georgia and Hawaii DOTs reported that they have observed the main causes for pavement distress as improperly placed asphalt mixture and also poorly maintained joint seal. Illinois DOT reported that the main causes of distress are expansion and contraction of joints at pavement/bridge interface, grade settlement and pavement expansion. ODOT reported the potential causes of pavement distress at bridge approaches include a saturated and/or weak subgrade, moisture infiltration into pavement (stripping), and differential loading responses between asphalt section and bridge ends. Occasionally, the bridge approaches have been evaluated as structurally deficient. SCDOT reported that temperature changes at problematic locations and variation in subgrade result in segregation. Also, difficulty in achieving optimal compaction at problematic lotions also results in poor pavement quality. MnDOT reported that distresses occur due to poor contractor workmanship. RIDOT noticed the potential causes of asphalt pavement damage are time and traffic. Mississippi DOT gave two main causes of pavement distress near bridge ends, which are inadequate compaction efforts of the base near the bridge ends and the bumping of the pavement from the movement of the approach/departure slabs over time. Maryland DOT opined that insufficient compaction at the abutment gives raise to pavement damage at bridge ends. NDOT said that the cracks at bridge approaches and departures appear due to saturated subgrade. MODOT and UDOT mentioned differential settlement between the pavement and bridge structure to be the cause of distresses near bridge approaches and departures. In Washington and Wisconsin states, the distresses are caused by thin asphalt structure and compression failure of underlying concrete.

3.2.3 M&R Strategies for Asphalt Pavements at Bridge Approaches and Departures

The final part of this survey seeks information on M&R strategies pursued by various state DOTs for asphalt pavements at bridge approaches and departures. There are three questions in this section:

6. *Are M&R activities more frequent on asphalt pavement sections at bridge approaches/departures than on regular asphalt pavement sections on highways in your state? Please explain the reasons.*
7. *Are there any special M&R strategies and guidelines for defective asphalt pavement sections adjacent to bridge approach/departure slabs in your state?*
8. *Please provide other comments regarding the performance of asphalt pavements adjacent to bridge approach/departure slabs in your state.*

For Question 6, 12 out of the 33 respondent states (Caltrans, GDOT, IDOT, Maryland DOT, Iowa DOT, KYTC, MiDOT, ODOT, SCDOT, Mississippi DOT, LADOT, and VDOT) said that they perform M&R activities more frequently at problematic locations. Caltrans informed that due to high load-induced stresses and bumps at problematic locations, the service life of pavements is reduced. Consequently, the frequency of rehabilitation measures at problematic locations is increased. GDOT and VDOT attributed the high frequency of maintenance activities in their respective states to the poor performance of asphalt at the bridge tie-in. In Illinois and Iowa, the multitude of potholes and settlement problems at bridge approaches and departures leads to frequent repairs. KYTC remarked that they are continually patching bridge ends with no end in sight. In Michigan, weak base gives rise to frequent repairs. ODOT takes additional maintenance activities such as leveling or patching that required more frequently in their state. In regard to rehabilitation, bridge approaches are typically evaluated at the same time as mainline pavement is unless otherwise needed. SCDOT informed that presence of a cold joint between the two different pavement types will give rise to pavement distresses. LADOT said that pavement distresses at problematic locations are more frequent due to the nature of the transition from a roadway structure to a bridge, and depending on the roadway pavement structure, the types of distresses and potential causes may vary. Mississippi DOT said that unless the pavement is in dire need of immediate repair the pavement will not get repaired until the surrounding roadway receives an overlay or a mill and overlay. Contrarily, Maryland DOT said that they perform M&R more frequently in order to add some wedge/level to bring the surface to the same level as the bridge when settlement occurs.

Responses to Question 7 of the survey showed that most participant states do not have special M&R strategies and guidelines for defective asphalt pavement sections adjacent to bridge approach/departure slabs. Some states mentioned their specific M&R techniques. These states include Arizona, Georgia, Illinois, Kentucky, Michigan, Tennessee, Utah, Virginia, Mississippi, Washington, and Wisconsin. AZDOT said they design thicker pavement sections next to bridge approaches when compared to the control section thickness. GDOT mainly follows steps like patching with both hot mix asphaltic concrete and cold-placed mastic type patching material. Illinois DOT has been following two major strategies, diamond grinding on decks and approaches and also laying 4 to 6 ft HMA expansion patches utilizing bituminous expansion particles. NDOT follows a special strategy of installing transverse pipe underdrains in granular trenches and using a drained foundation course under a rebuilt pavement. NMDOT's approach to counter this problem is to jack up the approaches by injecting cementitious grout or polyurethane into the subgrade/fill to correct the grade. In Tennessee (TDOT), in the event of settled approach slabs, slab jacking work has been used to repair the deficiency. ODOT said that bridge approaches and mainline pavement are evaluated according to the same design service life during a rehabilitation cycle unless reconstruction is needed. Maryland DOT maintenance forces monitor their respective areas and when the bridge ends get bad enough, maintenance will usually be performed by either of the following methods: blade path, mill/fill, using rut filling mastic ½ in rocks- this is very durable, and it is also self-leveling which makes for a smooth, quality, lasting fix. SCDOT does not have any special maintenance strategies at this time. However, they are experimenting with several mastic (plant resin) repair materials at problematic locations. LADOT utilizes a variety of rehabilitation techniques at problematic locations, their strategies include, full depth patching for base failures, flowable fill to underseal the area (e.g., voids under the approach slab, sealing off gaps in the abutment, etc.), partial depth patching, filling pot holes with cold mix and leveling with hot mix. In Mississippi the pavement is milled at a deeper depth than just the one lift the project requires. This is done to allow two or more lifts of asphalt to be laid up next to the approach/departure slabs.

The final question of this survey requests the respondents to provide comments regarding the performance of asphalt pavements adjacent to bridge approach/departure slabs in their state. Only 12 states (Alabama, Colorado, Florida, Georgia, Illinois, Kentucky, Nevada, South Dakota, Montana, Mississippi, Colorado and Tennessee) responded with comments.

ALDOT commented that full depth reconstruction is utilized at problematic locations in an attempt to provide significant structure to withstand the truck traffic loading. Florida remarked that pavement failures happen from the bottom up, whether it is settlement occurring due to lack of compaction, it will eventually make its way to the surface. Georgia DOT said that negligence of contractors will often lead to pavement damage at problematic locations. Illinois DOT opined that a specification must be issued for backfilling of abutments to get compaction instead of relying on engineering judgement. Kentucky commented that the idea of approach and departure slabs must be reevaluated. Nebraska commented that since they have a dry climate, they do not face too many problems at bridge approaches and departures. South Dakota DOT attached their "Bridge approach detail" to their response. Finally, Tennessee remarked that bridges and pavements being built by separate contractors leading to poor construction and subsequently, to damaged pavement. CDOT said that it is important to achieve proper compaction of asphalt pavements at bridge approach/departures-sometimes, which means adjusting the roller pattern. SCDOT opined that pavement distresses at problematic locations are always treated as first signs of more prevalent pavement distresses. LADOT remarked that, good drainage and proper confinement around end abutments are important for good health of asphalt pavements at any locations. MDT has recently developed a 30-year bridge end design memorandum (URL provided in the appendix). Mississippi DOT said that to alleviate the movement of the bridge end slabs, the slabs will sometimes be injected with expandable foam to raise them to the correct elevation and prevent them from moving.

3.3 Survey on Rehabilitation Techniques for Regular Asphalt Pavements with Vertical Alignment Constraint

Based on the feedbacks received from the nationwide questionnaire survey, three additional questions were sent to the same set of state DOT personnel to collect inputs on rehabilitation techniques for structurally deficient asphalt pavements under the constraint that the vertical alignment of the roadway cannot be changed. The three questions are:

1. *If you are experiencing alligator cracking due to inadequate pavement structure (e.g., inadequate asphalt pavement thickness, weak base or subbase layer), are there any methods or techniques specified by your agency, or most frequently used by contractors, as a permanent repair for the pavement, if the vertical alignment of the roadway could not be changed?*
2. *What are the typical or expected service lives of pavements repaired by the methods or techniques mentioned in the answers to the question above?*
3. *Is there any written rehabilitation guidelines used by your state DOT for asphalt pavement with insufficient structural capacity? If yes, could you send us the link?*

A total of 14 responses were received. The detailed responses from the participants are shown in Appendix B. The responses are summarized in Table 3-2**Error! Reference source not found.** for rehabilitation techniques for asphalt pavements with structural deficiency, and in Table 3-3 for ranges of typical service lives.

Table 3-2 Rehabilitation techniques for asphalt pavements with structural deficiency

State	Responses on Rehabilitation Techniques
Indiana	Reconstructing the base layer of asphalt pavement with cement stabilized or asphalt emulsion stabilized FDR techniques.
Georgia	For a typical resurfacing project, normally mark and repair the most severely damaged areas using deep patching. But eventually, the road will need to be either reconstructed or another process such as FDR and place enough asphalt pavement on this new base to account for traffic loading.
New York	Milling down 4 in or more to sound material, and resurfacing back up to existing elevation.
Rhode Island	If a structural deficiency is confirmed, the base layer material would be replaced with structural asphalt concrete according to the design period.
Colorado	Full depth patching is commonly used to address localized fatigue cracking with inadequate structure.
	Milling and functional overlay can be used to address large area fatigue cracking.
	Milling the surface about 3 in, placing 1 in HMA leveling course, and then placing a geogrid, and finally a 2 in overlay. In addition, structural improvements will have a minimum design life of 10 years for asphalt pavement rehabilitation (CDOT, 2017).

Table 3-2 Rehabilitation techniques for asphalt pavements with structural deficiency (continued)

State	Responses on Rehabilitation Techniques
Nevada	Partial depth patching is used to address localized fatigue cracking.
	Milling the existing surface and some of the aggregate base, stabilizing the base with 2% cement, and then compact and overlay with 3 - 4 in asphalt pavement.
Missouri	Stabilizing subgrade with polyurethane injection, then milling and overlay.
Washington	If the alligator cracking is not widespread, full depth asphalt patching would be considered for cracked areas. Then, milling and inlay would be used for the remaining pavement.
	Removing the existing pavement and underlying base and replacing with a new long-life (50 years) section if the pavement section would need periodic renewal in the form of milling and inlay.

Table 3-3 Typical range of empirical service lives for rehabilitation techniques

State	Rehabilitation Technique	Service Life (Years)
Indiana	Reconstruction	> 20
Georgia	Deep Patching	10
	Full Depth Reclamation	20
New York	Partial Depth Patching	2 - 4
	Milling and Inlay	8 - 12
Rhode Island	Milling and Inlay (to the base layer)	10 - 20
Missouri	Milling and Inlay (< 5 in)	7 - 12
	Thicker Milling and Inlay (> 5 in)	12 - 20
Washington	Mill and Inlay (3 - 4 in)	10 - 15
	Milling and Inlay (with full-depth patching)	10 - 20
	Reconstruction	50
Colorado	Full Depth Patching	< 15
	Milling and Functional Overlay	5 - 12
	Milling and Structural Overlay (with a geogrid)	10 - 14
Nevada	Partial Depth Patching	1 - 2
	Milling and Inlay (3 - 4 in, cement-stabilized base)	12 - 15

3.4 Follow-up Survey on Rehabilitation Techniques for Bridge Approach Pavements

For the nine state DOTs that indicated thin asphalt layers in their bridge approach pavements in the nationwide questionnaire survey, a follow-up survey was also conducted on their rehabilitation techniques for bridge approach pavements. The typical questions include:

1. *Are there any special M&R strategies and guidelines for defective asphalt pavement sections adjacent to bridge approach slabs in your state?*
2. *Is there a rule of thumb (or guideline, manual) for determining the thickness of milling and inlay for bridge approach pavement?*
3. *Based on your knowledge, what is the typical overlay thickness for bridge approach pavement in your state?*
4. *When will your state choose milling and inlay instead of patching for bridge approach pavements?*

Most responses in this follow-up survey indicated that bridge approach pavements would be evaluated in the same way as control sections. The detailed responses of the survey on rehabilitation techniques for bridge approach pavements are shown in Appendix C. The general rehabilitation practices for bridge approach pavements are patching (full-depth patching or partial-depth patching), milling and inlay (i.e., cold milling followed by asphalt overlay of the milled thickness), and reconstruction. Rehabilitation techniques implemented on bridge approach pavements are summarized in Table 3-4.

Table 3-4 Rehabilitation practices for bridge approach pavements

State	Responses on Rehabilitation Practice
Georgia	Partial-depth patching (1 - 2 in) and standard milling and inlay (1 - 2 in) are typically used to alleviate bridge approach pavement distresses.
Louisiana	Full-depth patching would be implemented if the base layer failed at bridge approach pavements.
Alabama	The extra-depth patching and extra-depth milling and inlay are used to address bridge approach pavement distresses. The specific patching depth is dependent on the total pavement thickness and the depth of cracking as observed by taking cores in the distressed area. Milling depth is typically set to remove most of the cracking. In addition, full-depth reconstruction is utilized for bridge approach pavement if the condition of the roadway requires reconstruction.
Mississippi	The bridge approach pavements are generally milled and resurfaced with the thickness of 3-4 in.
Montana	To alleviate bridge approach pavement distresses, three treatment options for different bridge approach pavement conditions are concluded as following: (1) To construct 30-year bridge approaches when either adjacent road or existing bridge need to be reconstructed; (2) If the roadway within 100 ft of the bridge approaches is showing increased signs of distress compared with the overall project roadway condition, mill an additional 0.2 ft (of existing asphalt pavement and/or base course) for the standard 200 ft transition and replace with new asphalt concrete.
Florida	Reconstruction with thicker asphalt layer is recommended for bridge approach pavement when its asphalt pavement thickness is not adequate.
Oregon	The minimum design life of reconstruction for bridge approach pavement is 30 years.
South Dakota	When reconstruction of bridge approach pavement is necessary, 6 in asphalt concrete and 12 in base course are generally paved. In addition, a layer of reinforcement fabric is typically placed beneath the base layer.

3.5 Survey on Current FDOT Rehabilitation Practices for Bridge Approach Pavements

A questionnaire survey of FDOT districts was conducted to collect current bridge approach pavement rehabilitation practices in Florida. The survey questions are designed as follows.

1. *Typically, what do you do to repair bridge approach pavements in your district?*
2. *What will be your rehabilitation plan for bridge approach pavements in the future?*
3. *Do you have any special M&R strategies and guidelines for bridge approach pavements?*
4. *Based on your M&R experience, have you noticed a thinner asphalt layer on bridge approach pavements than their control sections?*

The received responses are summarized in Table 3-5 for rehabilitation techniques for bridge approach pavements.

Table 3-5 Current FDOT rehabilitation practices for bridge approach pavements

District	Description of Rehabilitation Practice
1 & 7	The typical rehabilitation practice for bridge approach pavements is milling and resurfacing. In most cases, bridge approach pavements are suggested to be milled with the same depth as their control sections. Specially, a crack-relief geotextile is typically placed for bridge approach pavements with reflective cracking.
2	With consideration of several factors (e.g., number of bridges with severe bridge approach/departure asphalt pavement distresses, high traffic volume on Interstate highway, and the estimated repair costs), a short-term maintenance approach (e.g., patching, crack sealing, etc.) is commonly used to address the distresses (e.g., cracking, pothole, etc.). For the rehabilitation plan, a permanent repair would be performed if it is a localized problem and a short-term maintenance approach would be performed if it is beyond our capacity. In addition, the District Material Office investigated and discovered a much thinner wedge of asphalt immediately adjacent to the approach slab.
3	Bridge approach pavements are typically milled with a thickness of 2-3/4 in and resurfaced with 2 in Type SP SUPERPAVE structural asphalt and 3/4 in FC-5 friction course. In addition, several bridge approaches and departures were reconstructed with 8-1/2 in asphalt base, 2-1/2 in structural course, and 3/4 in FC-5 friction course.
4 & 6	As regards to thin bridge approach pavement, the original pavement design consisted of about 2 in asphalt concrete with lime-rock base. This was adequate for the traffic volume and loads at that time. Over the years, as traffic volume and loading increased, resurfacing has increased the thickness of control section except for bridge approach pavements. The latest resurfacing design include full-depth reconstruction for bridge approach pavements when the pavement structure is inadequate.
5	Bridge approach pavements are typically rehabilitated at the time their control sections are to be resurfaced. Then, if bridge approach pavements experienced significant distresses, a costlier repair approach would be expected. The rehabilitation strategy is deeper milling (e.g., even enter the base material) and asphalt inlay at bridge approaches to avoid the expense of reconstruction of bridge approach pavement. In addition, the differences of asphalt pavement thickness between bridge approach pavements and their control sections are typically noticed on old roadways which have been successively overlaid and resurfaced.

As can be seen from Table 3-5, the current rehabilitation practices for bridge approach pavements adopted by FDOT district offices include patching and crack sealing for short-term maintenance and repair, milling and inlay (including deep milling into the base layer) and full-depth reconstruction for long-term rehabilitation. For bridge approach pavements with reflective cracking, a geotextile is typically used during milling and inlay to reduce reflective cracking potential. In addition, bridge approach pavements are typically rehabilitated along with their control sections. Cold or hot in-place recycling was not mentioned as rehabilitation practices for bridge approach pavements.

3.6 Summary of Survey Results

Based on the nationwide survey results, many states noticed more distresses in asphalt pavements adjacent to bridge approach/departure slabs than in regular pavements. In some states, thinner asphalt layers were observed adjacent to a bridge approach/departure slab, primarily due to the practice of feathering down the asphalt layer during resurfacing to tie in at the bridge end slab to maintain grade. Many states attributed the excessive distresses in bridge approach pavements to inadequate compaction, insufficient drainage, and differential settlement. Over 30% states perform M&R activities more frequently on bridge approach pavements. However, many states evaluate and treat the bridge approach pavements in the same way as control sections and do not have special M&R strategies and guidelines for bridge approach/departure asphalt pavements.

In the current literature, some performance indicators were proposed to determine M&R needs for bridge approach pavements include differential settlement, approach-relative gradient, bridge approach index, and IRI.

Based on the responses from FDOT personnel and other state DOT agencies, the general rehabilitation techniques are crack sealing, patching (full depth patching or partial depth patching; hot patching or cold patching), asphalt wedging/leveling (rut-filling), milling and resurfacing, reconstruction for bridge approach/departure asphalt pavements, and compaction grouting (slab jacking) and chemical grouting, and reconstruction for approach slabs. In many states, pavement patches have to be placed at failed bridge approach pavement areas until the sections get resurfaced. For milling and resurfacing of bridge approach pavements in the states of Mississippi and Montana, the bridge approach/departure asphalt pavement would be milled to a deeper depth (1.5 - 2.4 in more) than control section to allow for a thicker asphalt layer. The rule of thumb for determining the depth of milling for a resurfacing project is normally based on the pavement condition survey, FWD testing, and cores taken from the roadway. Pavement condition survey can provide the percentage of distresses and the severity level. FWD testing will determine if additional structure is required for future traffic loading. Pavement cores reflect the severity and depth of cracking. Milling depth is typically set to remove the majority of cracking. Full depth reconstruction of bridge approach/departure asphalt pavement is typically adopted if the condition of regular pavement or bridge structure requires reconstruction. For reconstruction of bridge approach pavements in the states of Washington, Montana, and Oregon, pavement design life is normally longer than that of control sections. That is, the design thickness of asphalt layer in bridge approach/departure asphalt pavements should be larger than that in control sections.

CHAPTER 4 FLORIDA BRIDGE APPROACH AND DEPARTURE PAVEMENT DATA COLLECTION AND ANALYSIS

4.1 Introduction

To determine the extent and potential causes of distresses in bridge approach/departure asphalt pavements on Florida Interstate highways, relevant pavement condition data were collected and analyzed. Statistical models were developed to evaluate the possible factors influencing pavement performance and to help determine corresponding rehabilitation criteria.

The pavement condition data analyzed in this study came from two sources: FDOT highway video log images available at FDOT website, and 2014-2015 pavement condition survey data provided directly by the FDOT State Materials Office. The two-year pavement condition survey data were recorded for each 0.001 mi (5.3 ft) highway section, which allows the analysis for short pavement sections on bridge approaches/departures. A total of 1506 bridges were first identified on Florida Interstate highways. Among these bridges, 351 have concrete pavements on their approaches/departures and therefore were excluded. The analysis thus focused on the bridge approach/departure asphalt pavements for the remaining 1,155 bridges.

4.2 Pavement Condition Analysis Based on Video Log Images

The FDOT video log program records images of FDOT roadways, which can be searched and viewed from FDOT website based on the ID and mile posts of each roadway section.

4.2.1 Evaluation Procedure of Pavement Distresses Based on Video Log Images

The conditions of the bridge approach/departure asphalt pavements were visually assessed from the FDOT video log images, following guidelines in the FDOT 2015 Flexible Pavement Condition Survey Handbook (FDOT, 2015). Key steps in the survey process are discussed below.

In **Step 1**, the starting point of a bridge, as illustrated in Figure 4-1, was first identified based on the beginning mile post of the bridge. From this point going against the traffic direction, three rectangular segments were surveyed. The first segment is the approach slab, and the other two segments are each approximately 26 ft in length and usually 12 ft in width. Similarly, three more segments on the other side of the bridge were surveyed, including the departure slab and two 26 ft segments. The 26 ft segment length was selected due to convenience of data collection from video logs: any image visible on the video log web-screen moves to a 0.005 mi (26.4 ft) forward location with one click on the ‘Frame Forward’ button. Backward movement of any image is, similarly, in a 26.4 ft increment with each click on the ‘Frame Backward’ button.

In **Step 2**, the survey area was divided into five imaginary longitudinal sections, as shown in Figure 4-2. Effectively, the survey segment has two sub-segments: wheel path area and outside wheel path area.

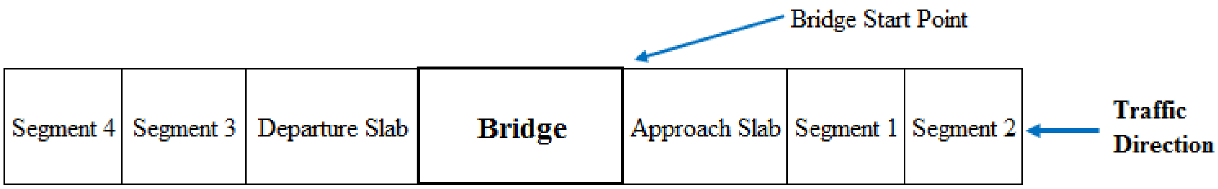


Figure 4-1 Schematic depiction of survey area in one lane around a bridge

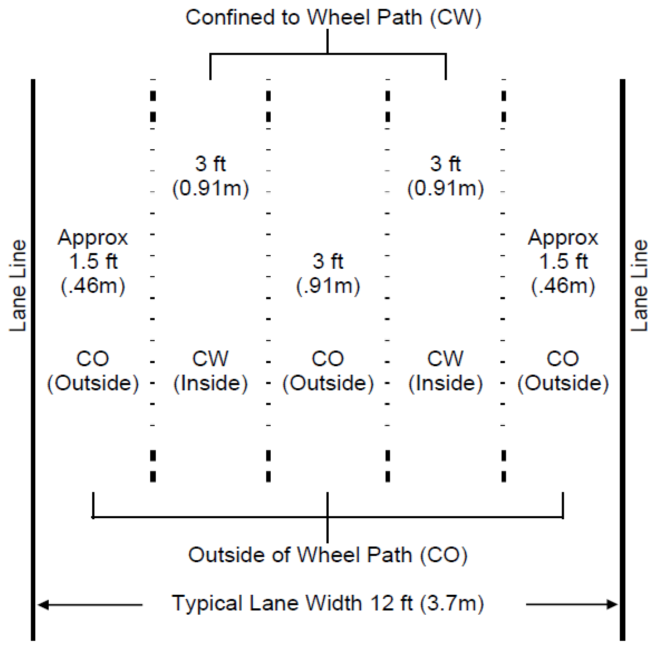


Figure 4-2 Wheel path designation in a lane (FDOT, 2015)

In **Step 3**, five distinct pavement distresses within each rectangular segment were assessed visually and recorded, including 1B Cracking, II Cracking, III Cracking, raveling, and patching. A brief description of each distress is provided as follows (FDOT, 2015).

- **1B Cracking:** Hairline cracks that are less than or equal to ⅛ in wide in either the longitudinal or the transverse direction. These may have slight spalling and slight to moderate branching.
- **II Cracking:** Cracks greater than ⅛ in and less than or equal to ¼ in wide in either the longitudinal or the transverse direction. These may have moderate spalling or severe branching. Also includes all cracks less than or equal to ¼ in wide that have formed cells less than 2 ft on the longest side, also known as alligator cracking.
- **III Cracking:** Cracks greater than ¼ in wide that extend in a longitudinal or transverse direction and cracks that are opened to the base or underlying material.
- **Raveling:** Raveling is the wearing away of the pavement surface caused by the dislodging of aggregate particles.
- **Patching:** A patch is an area of the pavement that has been replaced with a newer material after the time of original construction. Patching should reflect a defect in the pavement that has been repaired.

More details on the distress data collection procedure are available in the literature (FDOT, 2015).

In **Step 4**, a 26 ft lane section far away from the bridge (usually 0.3 - 0.5 mi away from the bridge) was selected as the control section. Pavement distresses on this section were assessed visually and recorded in a way similar to that in Step 3.

In **Step 5**, the recorded distress data were used to compute a crack rating (CR) for each segment on a scale of 0 to 10, with 0 representing severe pavement damage and 10 meaning no visible distress on the pavement. The average CR value of Segments 1 and 2 was used to represent the CR of the bridge approach pavement, while the average CR value of Segments 3 and 4 represented the CR of the bridge departure pavement.

Due to limitations of visual assessment of distresses from images, rutting was not identified or estimated. Patching and raveling were not separately recorded for within and outside wheel paths due to the difficulty in identifying the wheel-path/outside-wheel-path areas precisely from images. Instead, they were recorded for the entire segment. They were later assumed to be evenly distributed across the lane width in the data analysis. In most cases, available video logs were for only the outer lane of a highway. In some cases, the video logs were for the lane next to the outer lane. These two cases were not distinguished in the visual assessment. Instead, it was assumed that all the video logs were from the pavement design (truck) lane.

4.2.2 Analysis Results of Pavement Distresses Based on Video Log Images

The CR computed in the visual assessment was used as the pavement condition indicator for analyzing the extent of distresses in bridge approach/departure asphalt pavements. The analysis was performed for the entire state for each individual district, and for Interstate highway route. A general finding is that nearly one third of bridge approach/departure asphalt pavements exhibited more distresses than control sections.

4.2.2.1 Overall analysis and results

A summary of the CR for asphalt pavements at five distinct locations is presented in Figure 4-3. In this bar chart, each column represents an average value (shown in the column center) and the error bar on each column represents the range defined by one positive standard deviation and one negative standard deviation of the sample from the average value. As can be seen, overall the CR is similar for bridge approach pavements and departure pavements, with an average value of 9.1. This value is smaller than the average CR value of 9.5 from control sections, suggesting that on average the condition of bridge approach/departure asphalt pavements was worse than that of control sections. It is worthwhile to note that the approach/departure asphalt pavement conditions have higher variation than those of control sections.

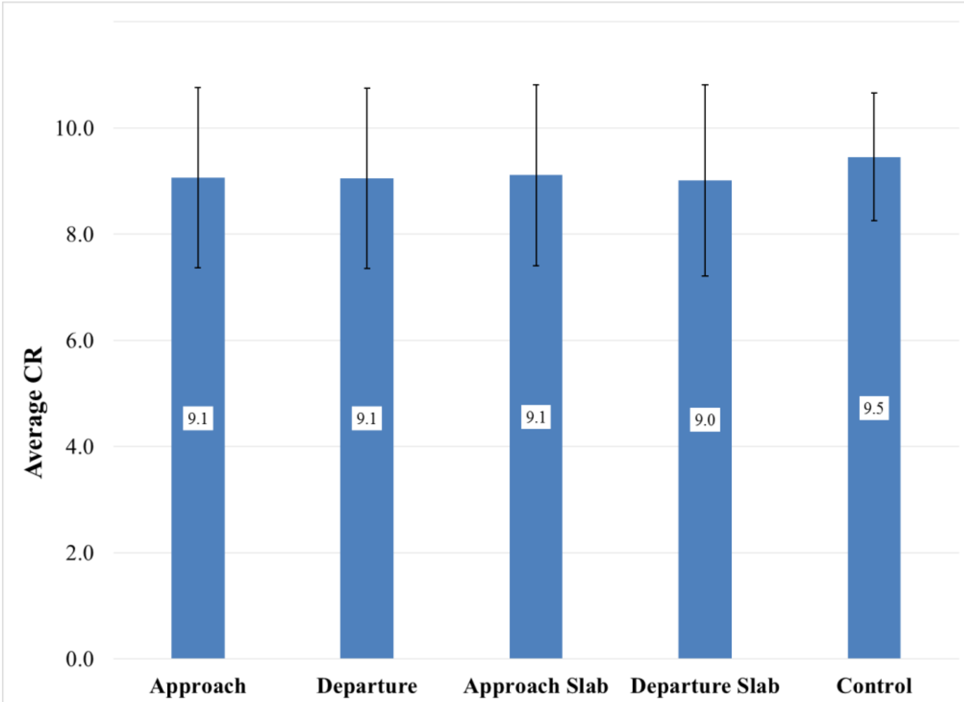


Figure 4-3 Summary of crack rating (CR) of asphalt pavements at all bridges

Among the 1,155 bridges surveyed, 317 bridges had a CR value of 9 or less for both approach and departure asphalt pavements. These approach/departure asphalt pavements showed a general trend of lower CR compared to control sections. On average, the CR is around 7.4 for bridge approach/departure asphalt pavements and 8.4 for control sections, as shown in Figure 4-4.

The overall CR differences between approach/departure asphalt pavements and control sections increase compared to the all-bridge scenario presented in Figure 4-3. Another important point is the drop of average control section CR from 9.5 in Figure 4-3 to 8.4 in Figure 4-4. This suggests that the condition of approach/departure asphalt pavements deteriorated faster than that of control sections.

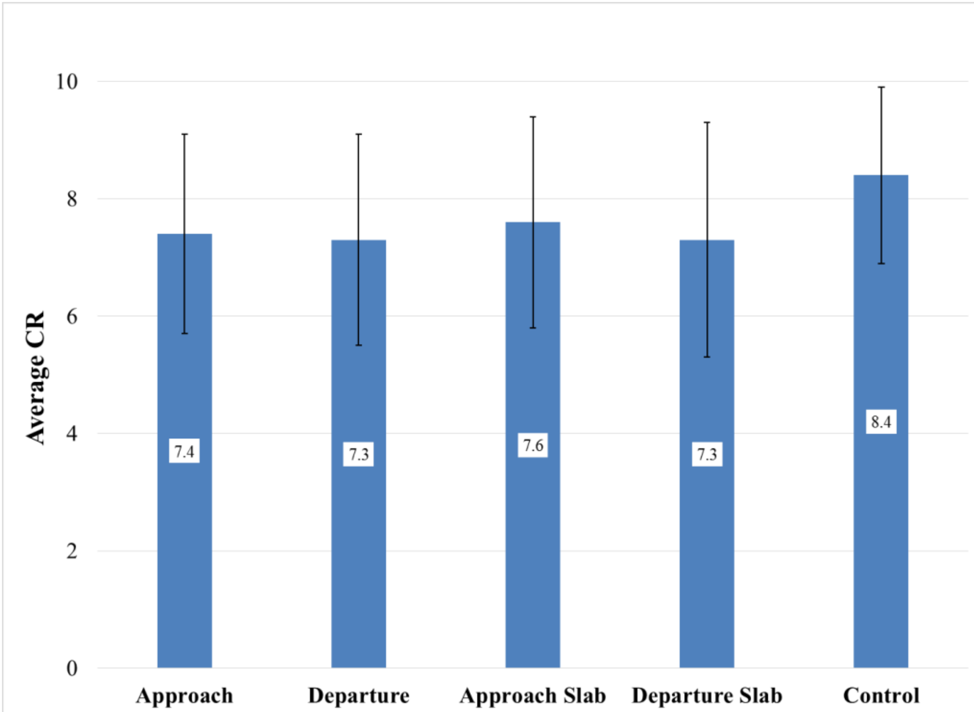


Figure 4-4 Summary of CR of asphalt pavements at bridges showing pavement distresses

Figure 4-5 shows the distributions of CR at approach, departure, and control sections. The pavement condition in general was good. At approaches and departures, nearly 85 percent segments showed CR values within a range of 8-10. At control sections, this group rises to over 90 percent which is even better. **Error! Reference source not found.** also reveals that nearly 15 percent of approach and departure asphalt pavements had a CR value below 8.

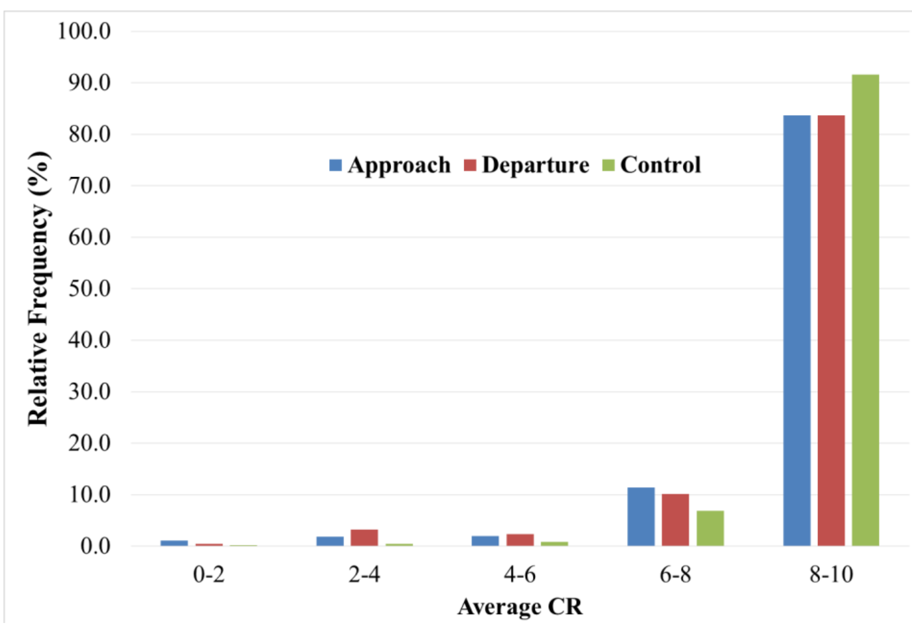


Figure 4-5 Distribution of CR

4.2.2.2 District-specific analysis and results
The distributions of the 1,155 bridges surveyed and the 317 bridges showing distresses in their approach/departure asphalt pavements across districts are presented in Table 4-1 and Figure 4-6. As can be seen, District 4 has the highest number of bridges showing distresses in their bridge approach/departure asphalt pavements, while District 3 has the lowest number.

Table 4-1 Distribution of bridges across districts

District	Number of Bridges	Number of Bridges Showing Pavement Distresses at Approach/Departure	Percentage of Bridges Showing Pavement Distresses at Approach/Departure
1	235	41	17
2	250	40	16
3	155	14	9
4	222	140	63
5	120	43	36
6	44	18	41
7	129	21	16
All	**1,155**	**317**	**27**

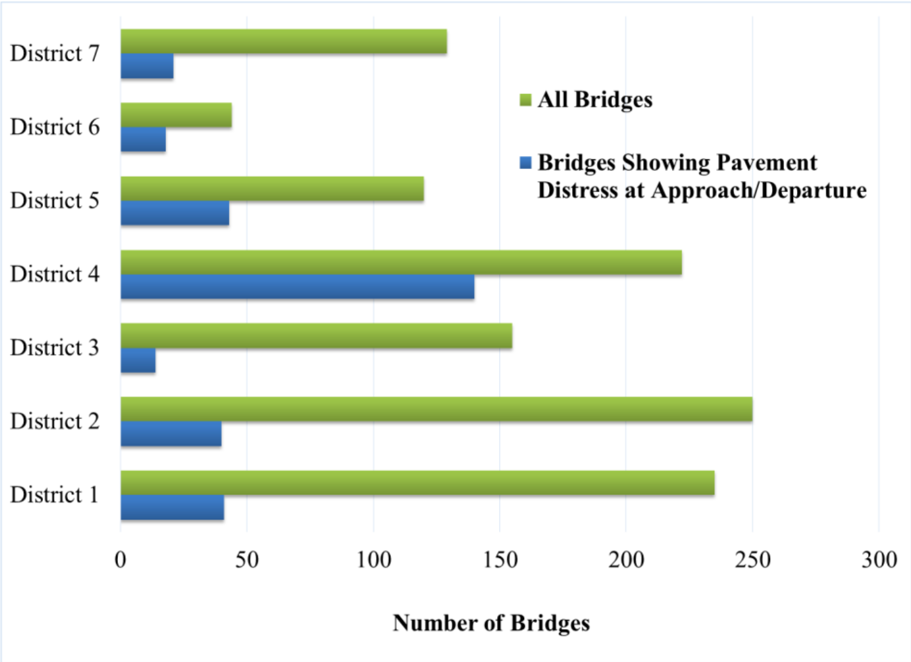


Figure 4-6 Distribution of bridges across districts

A summary of the CR for bridge approach/departure asphalt pavements and control sections is presented in Figure 4-7 for all bridges, and in Figure 4-8 for bridges showing pavement distresses. It can be seen from Figure 4-7 that on average Districts 4 and 5 have worse asphalt pavement conditions, both on bridge approaches/departures and control sections. Figure 4-8 shows that among bridges showing distresses in approach/departure asphalt pavements, on average Districts 1, 5, and 7 have relatively worse bridge approach/departure asphalt pavement condition than other districts.

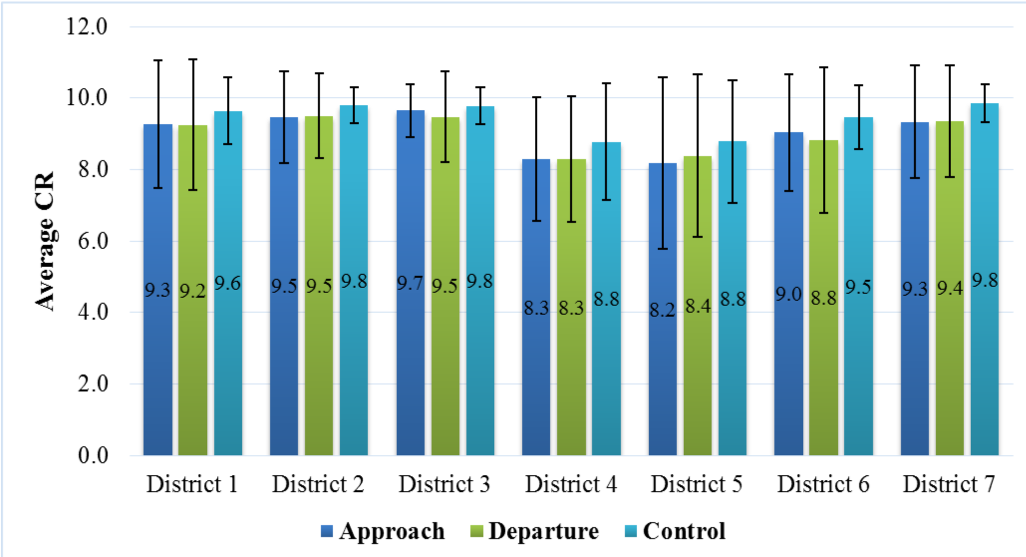


Figure 4-7 District comparison of asphalt pavement CR at all bridges

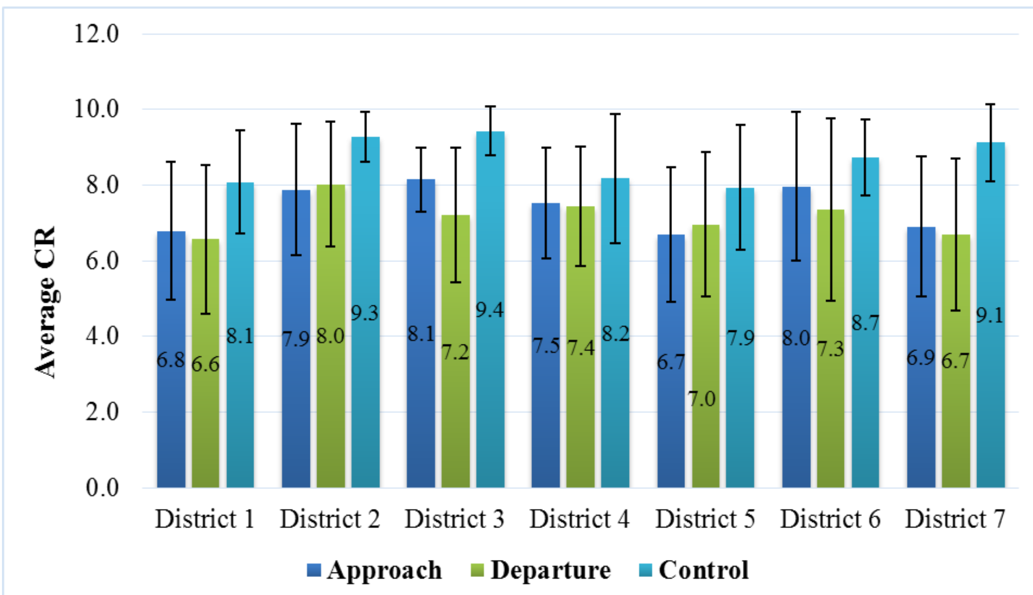


Figure 4-8 District comparison of asphalt pavement CR at bridges showing pavement distresses

4.2.2.3 Route-specific analysis and results

The distributions of the 1,155 bridges surveyed and the 317 bridges showing distresses in their approach/departure asphalt pavements across highway routes are presented in Table 4-2 and Figure 4-9. As can be seen, among the 1,155 bridges being analyzed, about 71 percent are on I-75, I-95, and I-10. I-75 and I-95, though, have a higher share of the 317 bridges showing pavement distresses than I-10. The percentage of bridges showing pavement distresses is 34 on I-75 and 52 on I-95.

Table 4-2 Distribution of bridges across routes

Interstate Highway Route	Number of Bridges	Number of Bridges Showing Distresses in Approach/Departure Asphalt Pavements	Percentage of Bridges Showing Distresses in Approach/Departure Asphalt Pavements
I-75	374	127	34
I-95	252	131	52
I-10	202	22	11
I-275	107	2	2
I-295	104	3	3
I-4	48	14	29
I-395	36	16	44
I-595	23	2	9
I-110	9	0	0
All	**1,155**	**317**	**27**

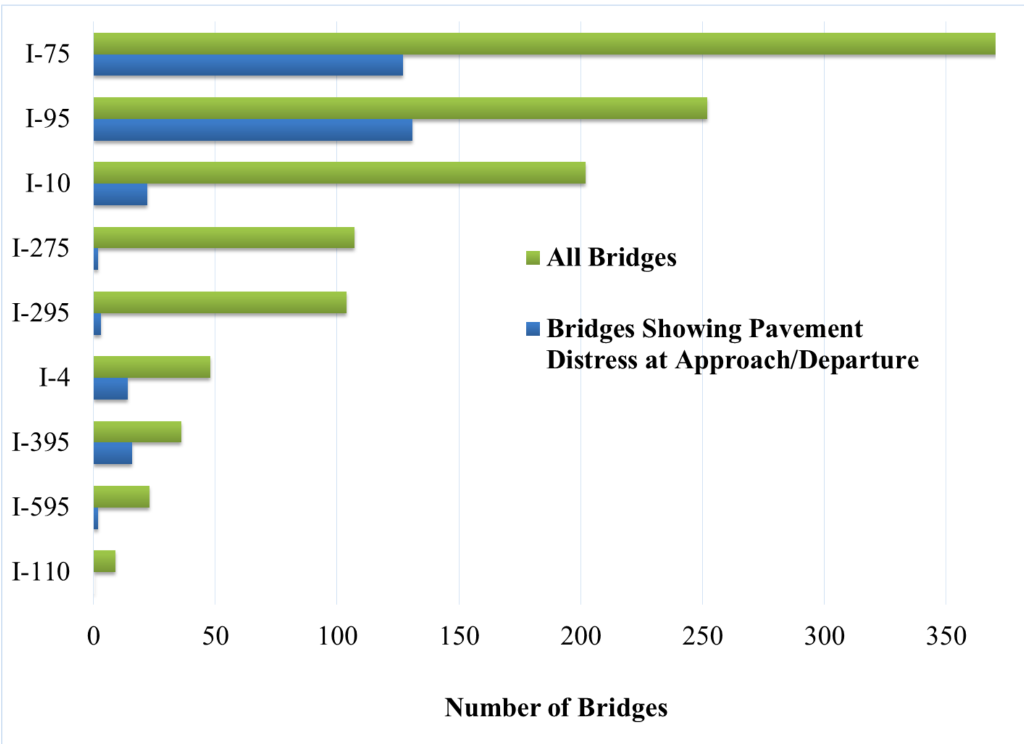


Figure 4-9 Distribution of bridges across routes

A summary of the CR for bridge approach/departure asphalt pavements and control sections is presented in Figure 4-10 for all bridges and in Figure 4-11 for bridges showing pavement distresses. It can be seen from Figure 4-10 that on average I-4, I-75, I-95, and I-395 have worse asphalt pavement conditions, both on bridge approaches/departures and control sections, than other Interstate highway routes. Figure 4-11 shows that on average I-75 has more pavement damage around bridges than other routes.

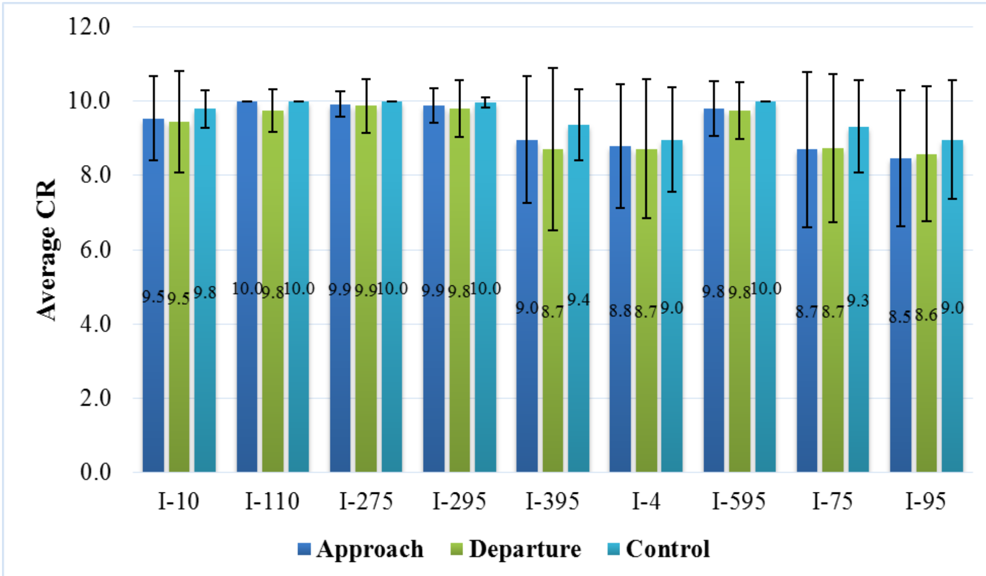


Figure 4-10 Route comparison of asphalt pavement CR at all bridges

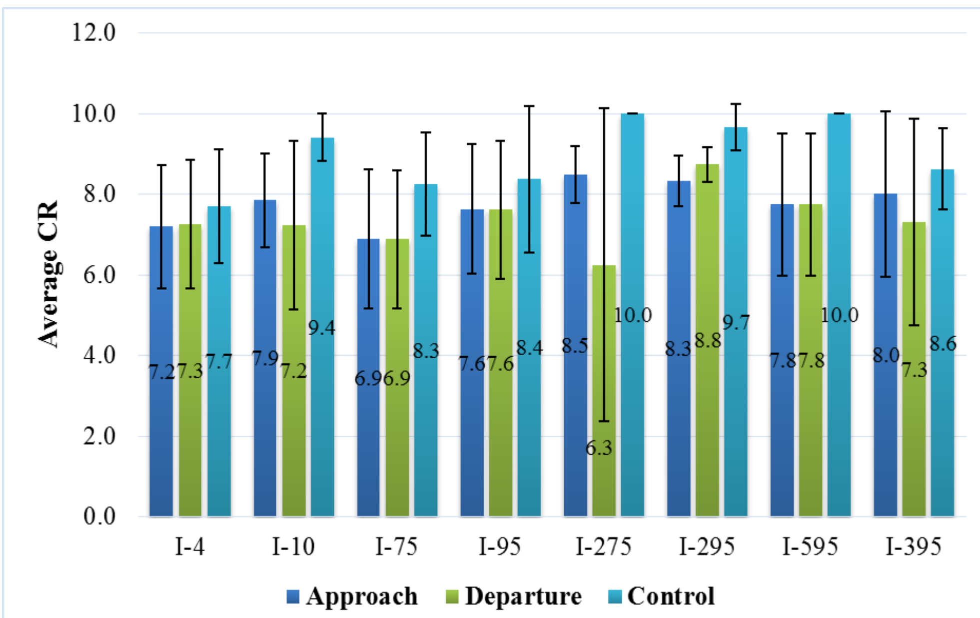


Figure 4-11 Route comparison of asphalt pavement CR at bridges showing pavement distresses

4.2.2.4 Hypothesis testing

The discussion in the previous sections was mainly based on the average CR values shown in Figure 4-3 through Figure 4-11. To make comparisons statistically rigorous, a paired t-test was performed to compare the CR values measured at two different locations. The null hypothesis in the t-test is that there is no difference between the mean values of CR at two locations. A 0.05 significance level (i.e., 95% confidence level) was selected for the t-test.

A summary of the pairs of locations compared and the two-tailed t-test results is shown in Table 4-3. The details of the t-test results are shown in Appendix D. It can be seen that, either based on all the 1,155 bridges surveyed or based on the 317 bridges showing distresses in their approach/departure asphalt pavements, the CR of bridge approach/departure asphalt pavements is statistically significantly different from that on control sections at the 95% confidence level. The difference in CR between approach pavement and approach slab, however, is not statistically significant. Similarly, the difference in CR between departure pavement and departure slab is statistically insignificant.

Table 4-3 Summary of hypothesis test results

	Based on All 1,155 Bridges		**Based on 317 Bridges Showing Pavement Distresses**	
Pair of Locations Compared	**Significant Pavement Condition Difference?**	**P-value**	**Significant Pavement Condition Difference?**	**P-value**
Approach, Control	Yes	0.000	Yes	0.000
Departure, Control	Yes	0.000	Yes	0.000
Approach, Approach slab	No	0.487	No	0.089
Departure, Departure slab	No	0.555	No	0.833
Approach, Departure	No	0.913	No	0.461

4.3 Pavement Condition Analysis Based on 2014-2015 Pavement Condition Data

FDOT publishes an annual pavement condition forecast report on its website, which contains pavement condition data over the last 16 years for each pavement section. The pavement sections included in this report, however, are generally several miles in length, spanning over one or several bridges. The performance data from that report do not differentiate bridge approach pavements from control sections, and therefore cannot be used in this study. Instead, a two-year (2014 and 2015) pavement condition data set with higher section resolution was provided directly by the FDOT State Materials Office (SMO). This data set contains pavement condition for each 0.001 mi (5.3 ft) highway section, in terms of rut depth, IRI, and ride number, and therefore is analyzed in this section.

4.3.1 Evaluation Procedure of Pavement Distresses Based on Condition Data

The beginning and ending mile posts of each of the 1,155 bridges included in this study were used to search for the needed pavement condition data from the given data set. A total of 1,013 bridges were identified in the data set. The other bridges were excluded due to missing condition data on either bridge approaches or bridge departures. For each identified bridge, the following steps were followed to evaluate pavement distresses.

In **Step 1**, the starting point of a bridge was first identified, as shown in Figure 4-12. From this point going against the traffic direction, four rectangular segments were selected. The first segment is the approach slab, and the other three segments (labelled as Approach 1, 2, and 3) are each approximately 95 ft in length and usually 12 ft in width. Similarly, four more segments on the other side of the bridge were selected, including the departure slab and three 95 ft segments (labelled as Departure 4, 5, and 6). Choice of 95 ft as the length of each segment was made due to the convenience of data collection from the FDOT pavement condition data set. Each approach or departure segment consists of 18 0.001-mi highway sections, which leads to a length of 0.018 mi (95 ft). The control section not shown in Figure 4-12 is usually 0.2 mi away from bridge approach/departure and is 105 ft in length. Pavement condition data from the control sections were used as benchmark for comparison with bridge approach/departure asphalt pavement conditions.

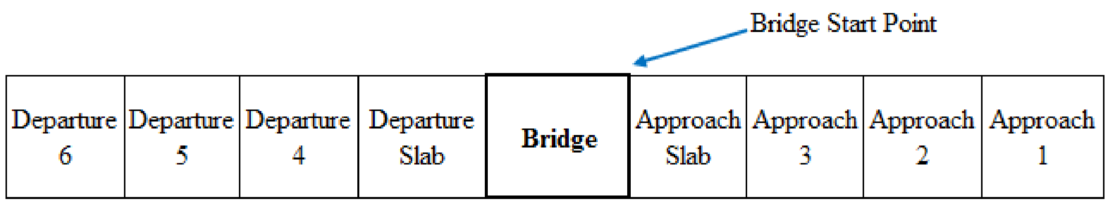


Figure 4-12 Schematic depiction of survey area in one lane around a bridge

In **Step 2**, the rut depth, IRI, and ride number information were extracted for each bridge approach/departure segment and control section.

In **Step 3**, Rut Rating and Ride Rating were computed for each segment from the rut depth, IRI, and ride number data, following the procedures in the literature (FDOT, 2015). The Rut Rating is obtained by subtracting from ten (10) the deduct value associated with the rut depth. A Rut Rating of 10 indicates a pavement with only minor rutting. The Ride Rating is converted from IRI, and is based upon a scale of 0 (very rough) to 10 (very smooth). A Ride Rating of 6 or less represents a relatively rough pavement. For the IRI, a value less than 95 in/mi is considered to represent good riding quality (FHWA, 2016).

4.3.2 Analysis Results of Pavement Distresses Based on Condition Data

The three pavement condition indices (i.e., Rut Rating, IRI, and Ride Rating) were used for analyzing the extent of distresses in bridge approach/departure asphalt pavements. The analysis was also performed for three scenarios: entire state, district, and route.

4.3.2.1 Overall analysis and results

A summary of the three condition indices on bridge approach and departure pavements and on control sections for all the 1,013 bridges is presented in Table 4-4 and Figure 4-13 through Figure 4-15. A summary of paired t-test results for Rut Rating and IRI are shown in Table 4-5, with details of the t-test results shown in Appendix D. As can be seen from Table 4-4, the average Rut Rating is slightly higher on bridge approach/departure asphalt pavements than on control sections, indicating less rutting on bridge approaches/departures. This difference is statistically significant at the 95% confidence level between the control section and Approaches 2 and 3 or Departures 4 and 5, as shown in Table 4-5. The average IRI and Ride Rating values, however, show that the bridge approach/departure asphalt pavements are significantly rougher than control sections. It may also be observed that the closer to the approach/departure slabs, the rougher the pavement becomes. Such difference is statistically significant, as shown in Table 4-5.

Table 4-4 Average pavement condition indices for all bridges

Condition Index	Approach 1	Approach 2	Approach 3	Departure 4	Departure 5	Departure 6	Control Section
Rut Rating	9.3	9.3	9.3	9.4	9.3	9.3	**9.2**
IRI	77	81	94	113	95	81	**64**
Ride Rating	7.7	7.7	7.5	7.3	7.5	7.7	**7.9**

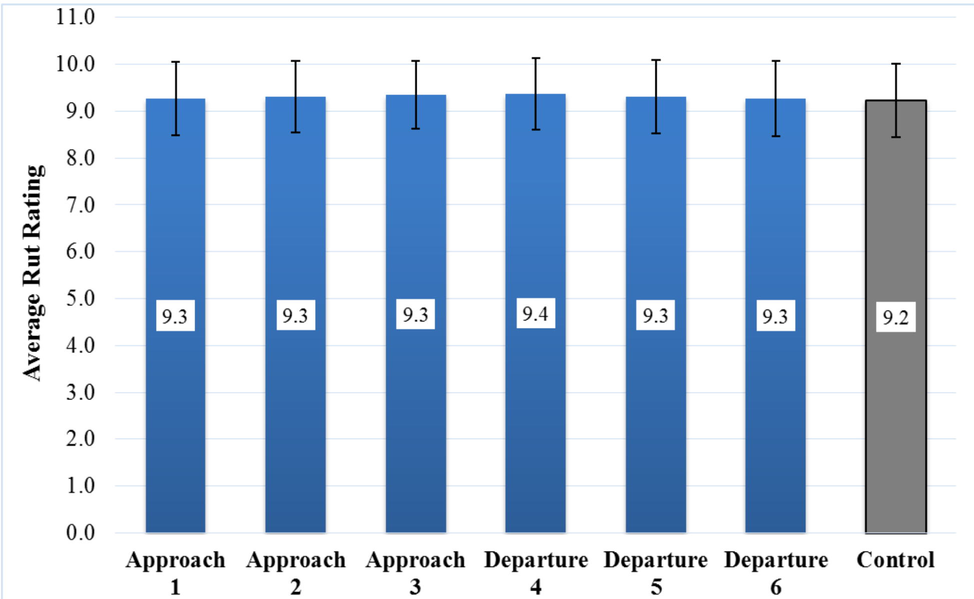


Figure 4-13 Summary of rut rating for all bridges

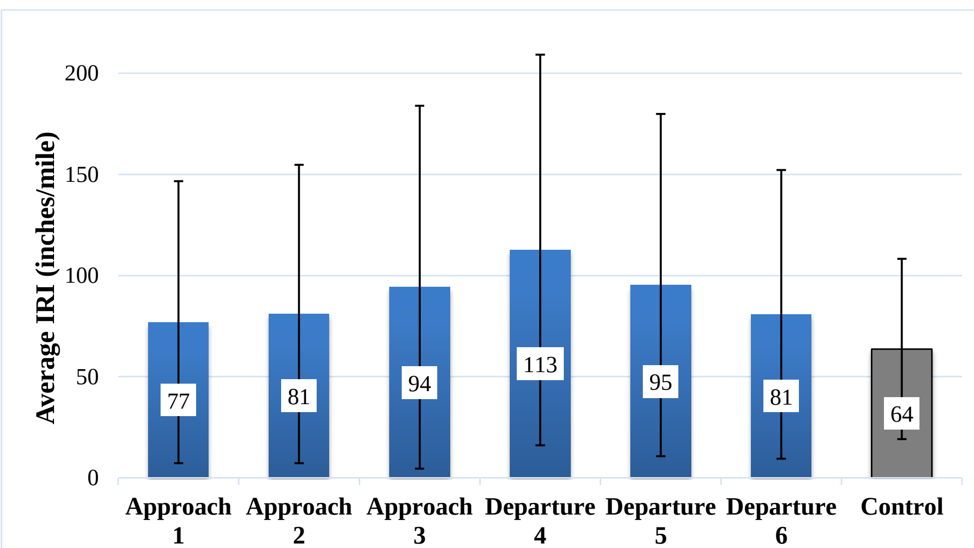


Figure 4-14 Summary of IRI for all bridges

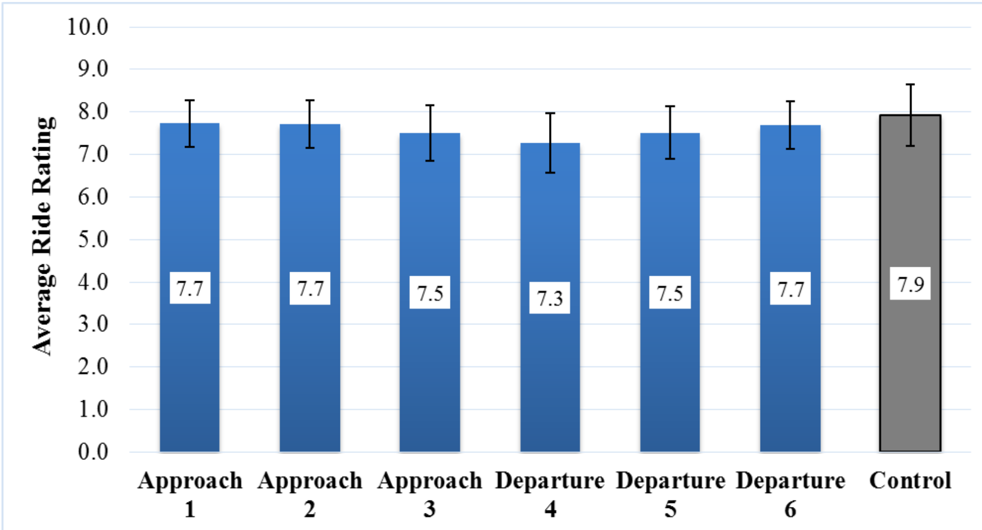


Figure 4-15 Summary of ride rating for all bridges

Table 4-5 Summary of hypothesis test results of rut rating and IRI

Condition Index	Pair of Locations Compared	Significant Difference in Pavement Condition?	P-value
Rut Rating	Approach 1, Approach 2	No	0.313
	Approach 2, Approach 3	No	0.130
	Approach 1, Approach 3	Yes	0.010
	Approach 1, Control	No	0.127
	Approach 2, Control	Yes	0.012
	Approach 3, Control	Yes	0.000
	Departure 4, Departure 5	Yes	0.032
	Departure 5, Departure 6	No	0.245
	Departure 4, Departure 6	Yes	0.001
	Departure 4, Control	Yes	0.000
	Departure 5, Control	Yes	0.001
	Departure 6, Control	No	0.154
IRI	Approach 1, Approach 2	No	0.059
	Approach 2, Approach 3	Yes	0.000
	Approach 1, Approach 3	Yes	0.000
	Approach 1, Control	Yes	0.000
	Approach 2, Control	Yes	0.000
	Approach 3, Control	Yes	0.000
	Departure 4, Departure 5	Yes	0.000
	Departure 5, Departure 6	Yes	0.000
	Departure 4, Departure 6	Yes	0.000
	Departure 4, Control	Yes	0.000
	Departure 5, Control	Yes	0.000
	Departure 6, Control	Yes	0.000

Figure 4-16 summarizes the number of bridges with either approach pavements or departure pavements showing distresses (i.e., Rut Rating less than 9, IRI greater than 95 in/mi, or Ride Rating greater than 7). Out of the 1,013 bridges considered, around 200 bridges have noticeable rutting in their approach or departure pavements, but there are around 280 bridges whose corresponding control sections have noticeable rutting. In terms of IRI, around 363 bridge approach pavements and about 543 bridge departure pavements have rough condition (IRI greater than 95 in/mi), which is significantly more than the number of control sections (around 85). Among all the bridges whose control sections have good riding condition (i.e., IRI lower than 95 in/mi), there are about 30% of bridges showed worse riding condition (i.e., IRI greater than 95 in/mi) on their approach pavements, and about 50% of bridges showed worse riding conditions on their departure pavements.

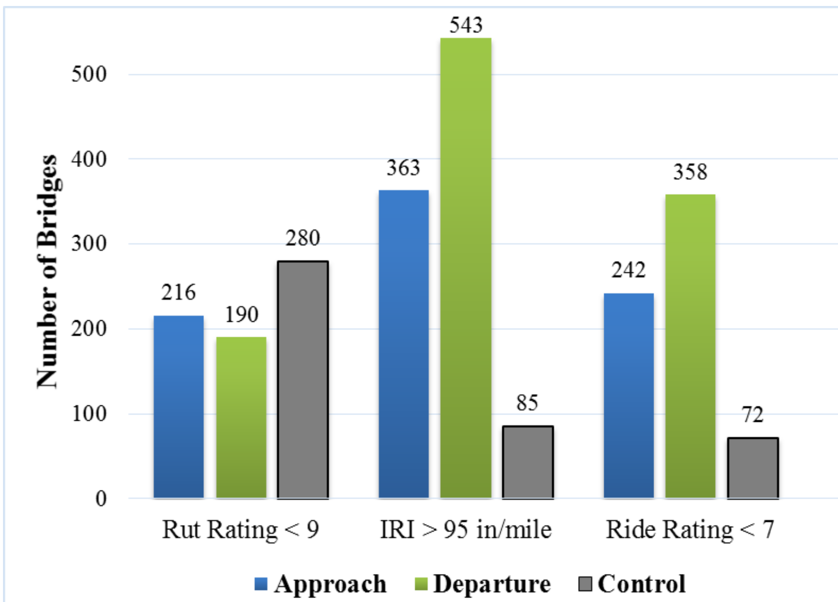


Figure 4-16 Number of bridges with pavement condition indices indicating distresses

4.3.2.2 Rut rating analysis and results

In this section, Rut Rating of bridge approach/departure asphalt pavements is analyzed for Florida districts and Interstate highway routes. Different from the analysis in the previous section which used three approach (departure) segments to represent the approach (departure) pavement, the analysis in this section only uses one segment (Approach 3 or Departure 4 as shown in Figure 4-12) to represent the approach or departure asphalt pavement. Such a change was made because the previous analysis showed that the segment closer to the approach (departure) slab has worse (rougher) condition.

The distributions of all the bridges considered and the bridges showing a Rut Rating less than 9 on both approach and departure asphalt pavements across districts are presented in Table 4-6. As can be seen, District 5 has the highest number of bridges showing signs of rutting on their approach/departure asphalt pavements, followed by District 3 and District 7.

Table 4-6 Distribution of rut rating across districts

District	Number of Bridges	Number of Bridges Showing Rut Rating less than 9 at Approach & Departure	Percentage of Bridges Showing Rut Rating less than 9 at Approach & Departure
1	233	10	4
2	203	12	6
3	128	18	14
4	207	16	8
5	102	22	22
6	37	0	0
7	103	10	10
All	**1,013**	**88**	**9**

A summary of the Rut Rating for all the bridges across districts is presented in Figure 4-17. It can be seen that the average Rut Rating is slightly lower on the control sections than on the bridge approach/departure asphalt pavements in all districts except District 6.

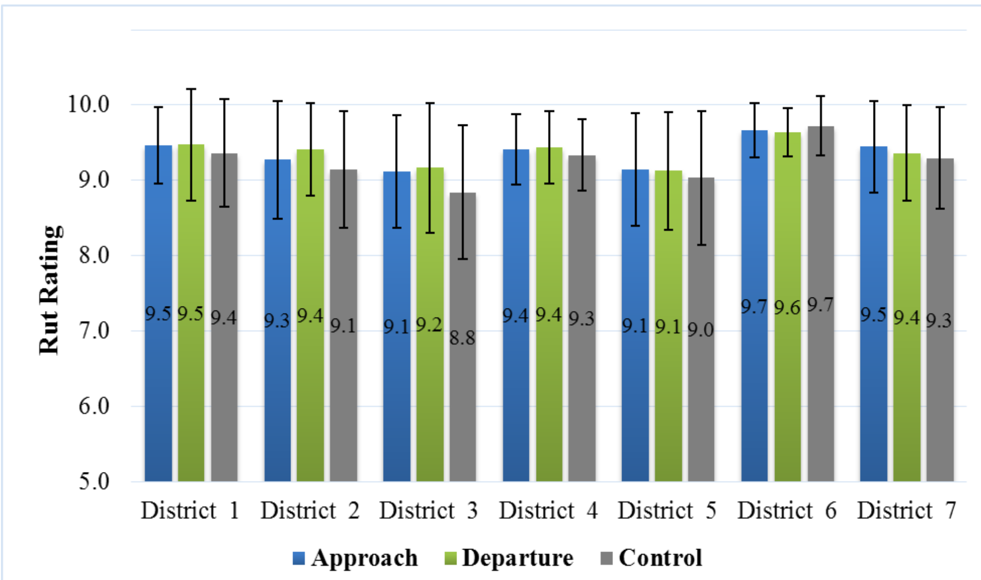


Figure 4-17 District comparison of asphalt pavement rut rating at all bridges

The distribution of the bridges showing a Rut Rating less than 9 on both approach and departure asphalt pavements across highway routes is presented in Table 4-7. As can be seen, on I-10, I-4, and I-95, relatively more percentage of bridges showed signs of rutting on both approach and departure asphalt pavements.

Table 4-7 Distribution of rut rating across routes

District	Number of Bridges	Number of Bridges Showing Rut Rating less than 9 on Both Approach and Departure Pavements	Percentage of Bridges Showing Rut Rating less than 9 on Both Approach and Departure Pavements
I – 10	165	22	13
I – 110	5	0	0
I – 275	99	9	9
I – 295	104	5	5
I – 395	36	0	0
I – 4	46	9	20
I - 595	19	1	5
I – 75	335	19	6
I – 95	204	23	11
All	**1,013**	**88**	**9**

A summary of the Rut Rating for all the bridges across routes is presented in Figure 4-18. It can be seen that the average Rut Rating is slightly lower on the control sections than on the bridge approach/departure asphalt pavements on most routes.

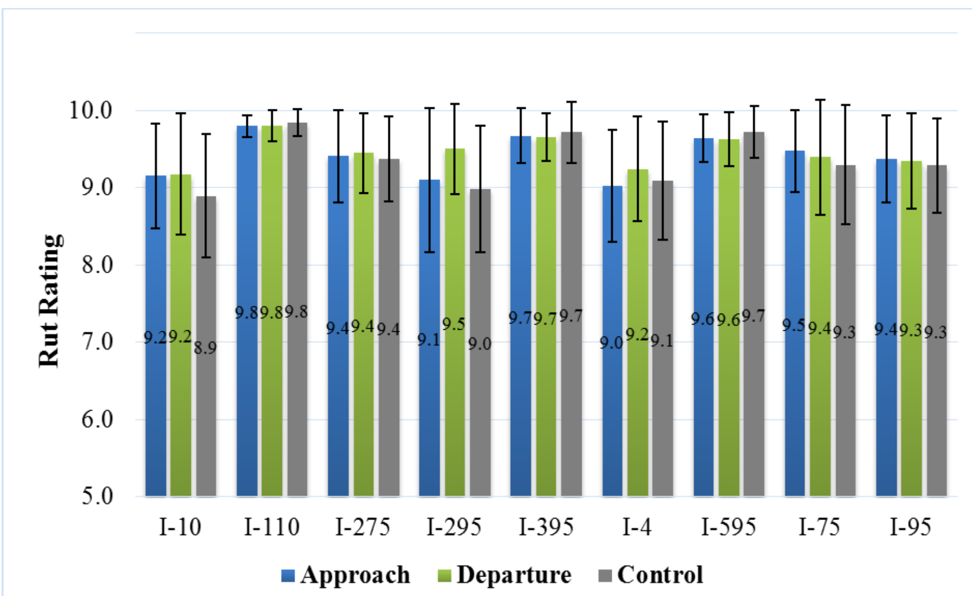


Figure 4-18 Route comparison of asphalt pavement rut rating at all bridges

4.3.2.3 IRI analysis and results

In this section, IRI of bridge approach/departure asphalt pavements is analyzed for Florida districts and Interstate highway routes. Similar to the Rut Rating analysis, the analysis only uses one segment (Approach 3 or Departure 4) to represent the approach or departure asphalt pavement.

The distributions of all the bridges considered and the bridges showing an IRI greater than 95 in/mi on both approach and departure asphalt pavements across districts are presented in Table 4-8 and Figure 4-19. As can be seen, District 5 has the highest percentage of bridges showing a high IRI value on both approach and departure asphalt pavements, followed by District 7 and District 4.

Table 4-8 Distribution of IRI across districts

District	Number of Bridges	Number of Bridges Showing IRI greater than 95 in/mi on Both Approach and Departure Pavements	Percentage of Bridges Showing IRI greater than 95 in/mi on Both Approach and Departure Pavements
1	233	19	8
2	203	19	9
3	128	8	6
4	207	29	14
5	102	27	26
6	37	4	11
7	103	17	17
All	**1,013**	**123**	**12**

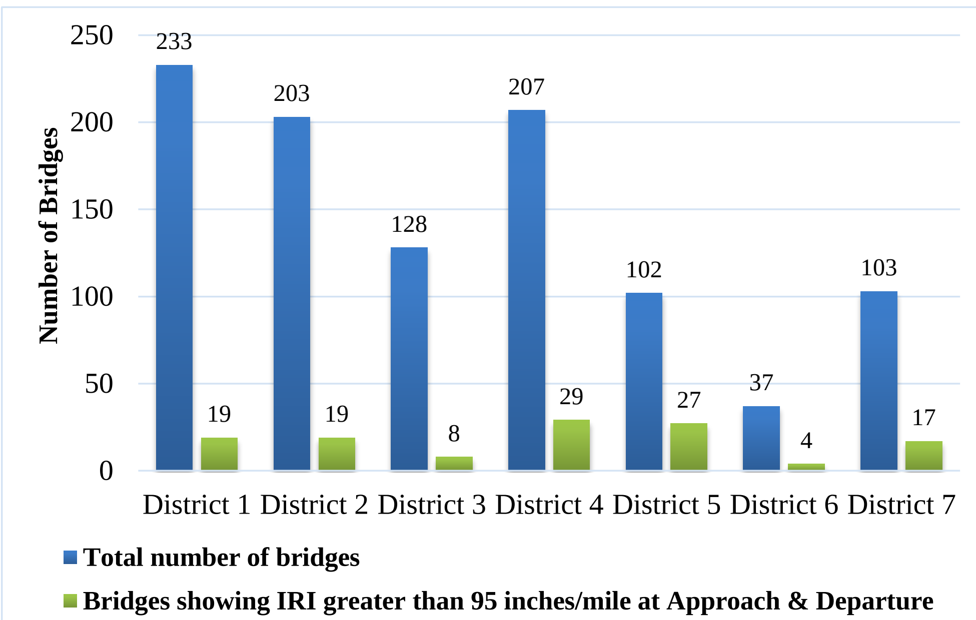


Figure 4-19 Share of bridges in each district showing IRI greater than 95 in/mi on both approach and departure pavements

A summary of the IRI across districts is presented in Figure 4-20 for all bridges, and in Figure 4-21 for bridges showing IRI greater than 95 in/mi on both approach and departure asphalt pavements. It can be seen that the bridge approach/departure asphalt pavement IRI is significantly larger than the control section IRI in all districts. Departure pavement IRI is generally larger than approach pavement IRI in all districts. This is consistent with the findings in the literature (Long et al., 1998).

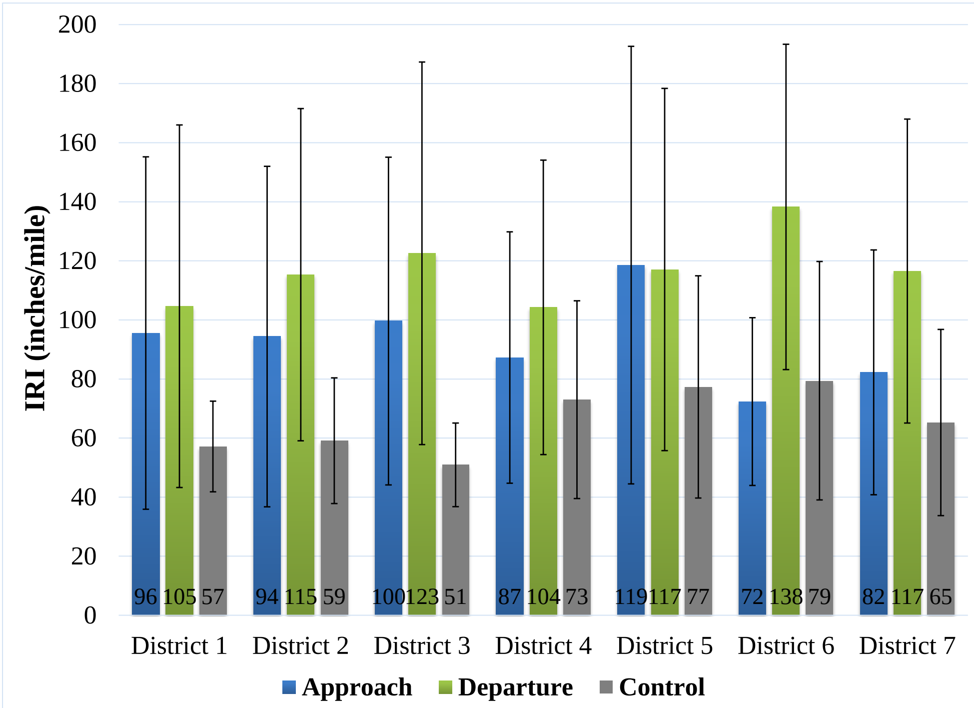


Figure 4-20 District comparison of asphalt pavement IRI at all bridges

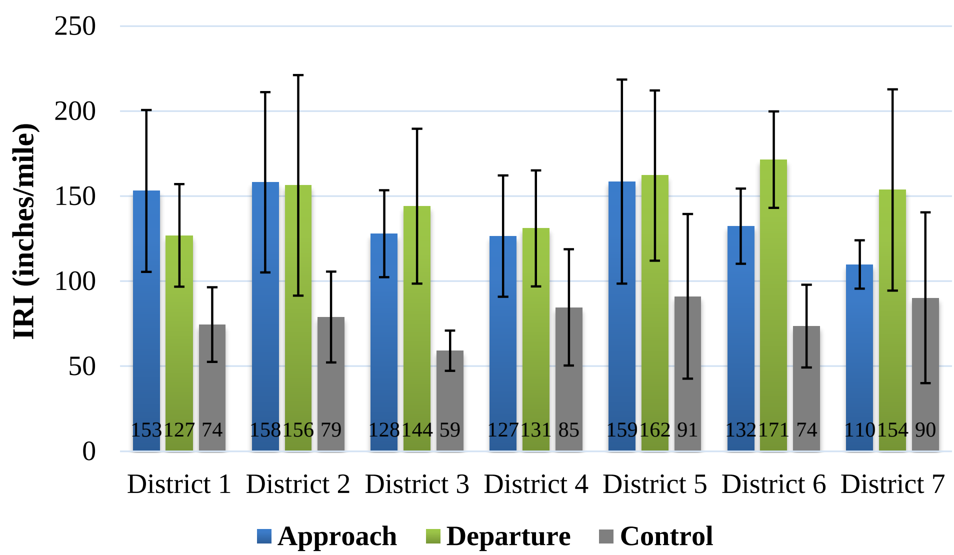


Figure 4-21 District comparison of IRI at bridges showing IRI greater than 95 in/mi on both approach and departure pavements

The distributions of all the bridges considered and the bridges showing an IRI greater than 95 in/mi on both approach and departure asphalt pavements across Interstate highway routes are presented in Table 4-9 and Figure 4-22. As can be seen, I-4, I-95, and I-275 have higher percentage of bridges showing IRI greater than 95 in/mi on both approach and departure asphalt pavements.

Table 4-9 Distribution of IRI across routes

Interstate Highway Route	Number of Bridges	Number of Bridges Showing IRI greater than 95 in/mi on Both Approach and Departure Pavements	Percentage of Bridges Showing IRI greater than 95 in/mi on Both Approach and Departure Pavements
I – 10	165	8	5
I – 110	5	0	0
I – 275	99	16	16
I – 295	104	10	10
I – 395	36	4	11
I – 4	46	13	28
I - 595	19	1	5
I – 75	335	34	10
I – 95	204	37	18
All	**1,013**	**123**	**12**

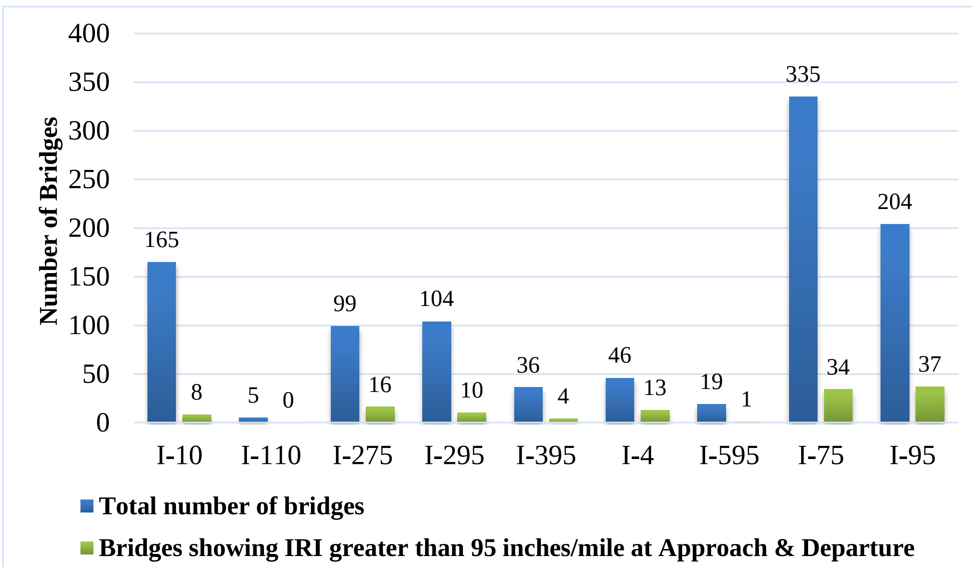


Figure 4-22 Share of bridges on each route showing IRI greater than 95 in/mi on both approach and departure pavements

A summary of the IRI across routes is presented in Figure 4-23 for all bridges, and in Figure 4-24 for bridges showing IRI greater than 95 in/mi on both approach and departure asphalt pavements. It can be seen that the bridge approach/departure asphalt pavement IRI is significantly higher than the control section IRI on all routes. Departure pavement IRI is generally higher than approach pavement IRI on most routes.

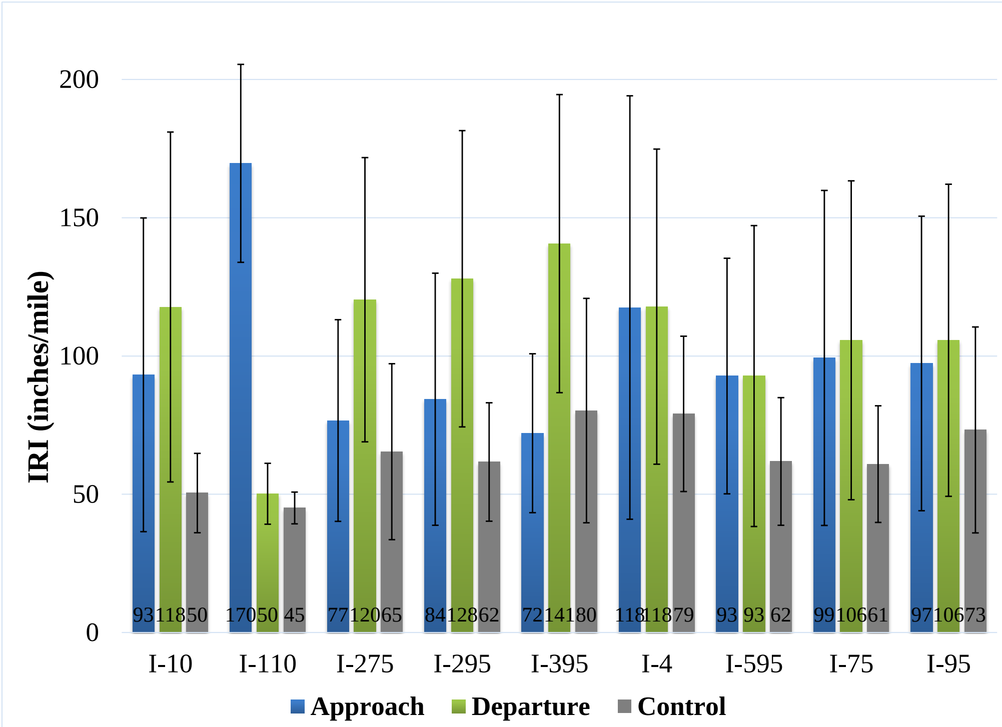


Figure 4-23 Route comparison of asphalt pavement IRI at all bridges

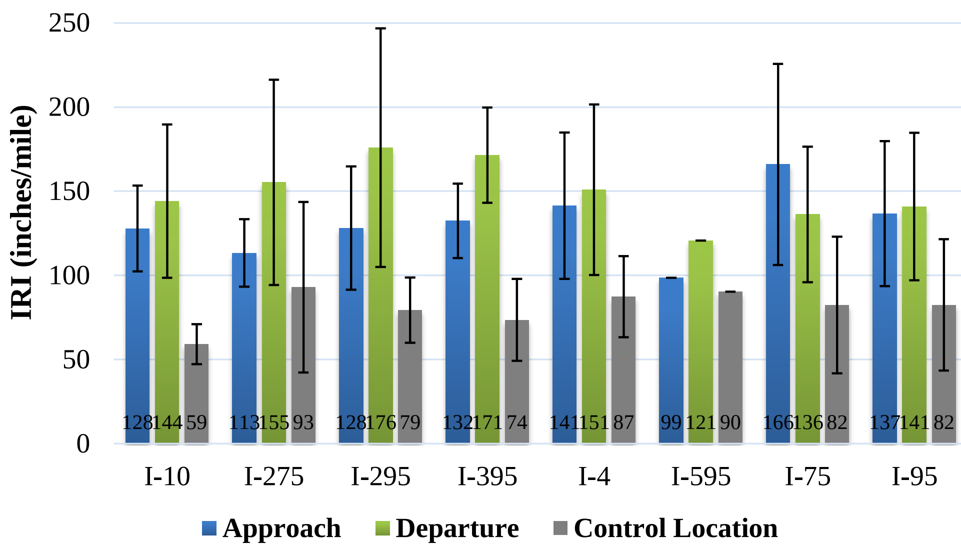


Figure 4-24 Route comparison of IRI at bridges showing IRI greater than 95 in/mi on both approach and departure pavements

Since Ride Rating is inversely correlated with IRI, it was not further analyzed for the district and route scenarios. It is expected that findings from its analysis should be similar to those from the IRI analysis.

4.4 Asphalt Layer Thickness Analysis

As discussed in the literature review, in several FDOT pavement projects there existed a very thin asphalt layer adjacent to a bridge approach/departure slab, which contributed to excessive distresses in the pavement. The nationwide survey revealed that around 30% of the states surveyed had experienced the thin asphalt layer issue in their bridge approach/departure asphalt pavements. It is, therefore, worthwhile to investigate the asphalt layer thickness near the bridges analyzed in this study.

FDOT does not maintain a statewide highway pavement structure database. Instead, a ground penetration radar (GPR) data set is available from the FDOT SMO. This data set contains asphalt layer thickness for a portion of the state highway network, which includes 113 bridges with asphalt approach/departure pavements. This is about 10% of the Florida Interstate highway bridges with approach/departure asphalt pavements.

4.4.1 GPR Data Selection Method

The GPR data were recorded at a varying spacing (i.e., pavement section length) on different highways, as summarized in Table 4-10. For the GPR data recorded at a spacing of 100 ft, only two data points were taken as representation of a bridge approach or departure pavement. This is based on the assumption that at a distance of beyond 200 ft from the bridge approach or departure slab, pavement sections may not well represent the bridge approach or departure pavements. The two data points were used to calculate the average asphalt layer thickness on the bridge approach or departure. For the GPR data recorded at a smaller spacing (5.28 ft), more data points were used to calculate the average thickness. A control section was selected at a distance of 0.2-0.3 mi away from each bridge to calculate the average asphalt layer thickness of control sections.

Table 4-10 GPR data point spacing

Data Point Spacing (ft)	Number of Bridges	Number of Data Points at Approach/Departure	Number of Data Points at Control Section
100	83	2	3
47-50	25	2	3
5.28	5	6	6

4.4.2 General Asphalt Layer Thickness Trends

The average asphalt layer thicknesses for different pavement sections are shown in Figure 4-25. As can be seen, for the 113 bridges investigated, the average asphalt layer thickness is significantly lower (about 2 in less) on bridge approaches or departures than on control sections.

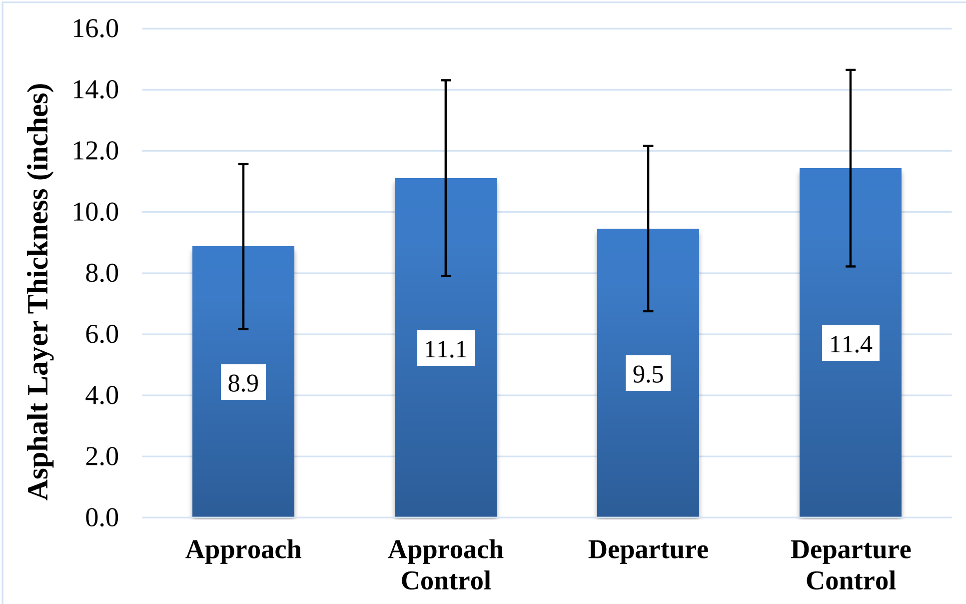


Figure 4-25 Comparison of asphalt layer thickness

4.4.3 District-Specific Asphalt Layer Thickness Trends

The number of bridges with available GPR data in each district is shown in Table 4-11. Note that there is no GPR data for Districts 3 and 6. The average asphalt layer thicknesses for different pavement sections are shown in Figure 4-26 for each district. As can be seen, District 5 has the lowest asphalt layer thickness on bridge approaches/departures. This trend, however, may not represent the actual scenario since the sample size is very small (GPR data are available for only 6 bridges in District 5). The difference in asphalt layer thickness between bridge approach/departure asphalt pavements and control sections is most significant in District 2, with an average value around 5 in, followed by District 5.

Table 4-11 GPR data availability in districts

District	Number of Bridges	Number of Bridges with Available GPR Data
1	235	38
2	250	32
3	155	0
4	222	27
5	120	6
6	44	0
7	129	10
All	**1,155**	**113**

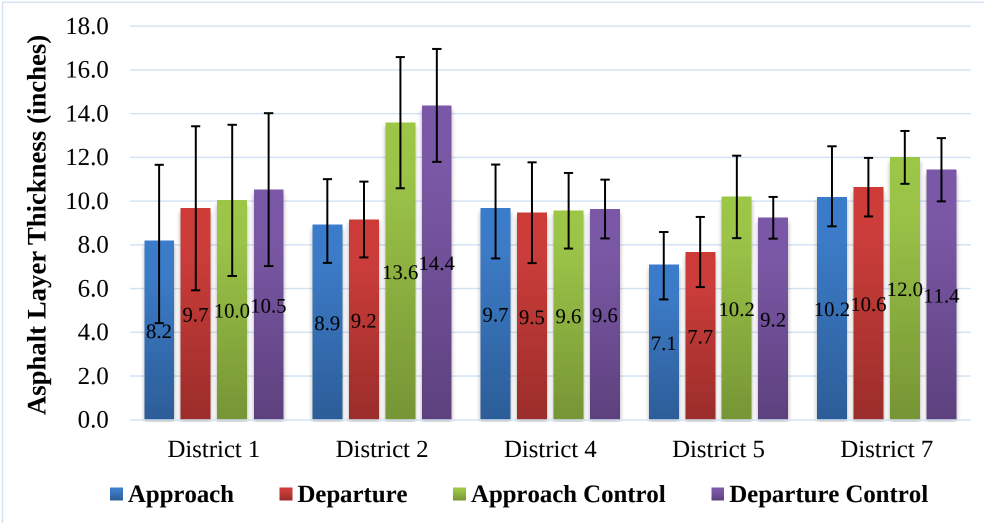


Figure 4-26 Comparison of asphalt layer thickness across districts

4.4.4 Route-Specific Asphalt Layer Thickness Trends

The number of bridges with available GPR data on each route is shown in Table 4-12. As can be seen, the available GPR data are mainly from I-75 and I-95. The average asphalt layer thicknesses for different pavement sections are shown in Figure 4-27 for the three routes. It can be seen that the difference in asphalt layer thickness between bridge approach/departure asphalt pavements and control sections is more significant on I-75 than on I-95.

Table 4-12 GPR data availability on routes

Route	Number of Bridges	Number of Bridges with Available GPR Data
I - 75	374	66
I - 95	252	43
I - 275	107	4

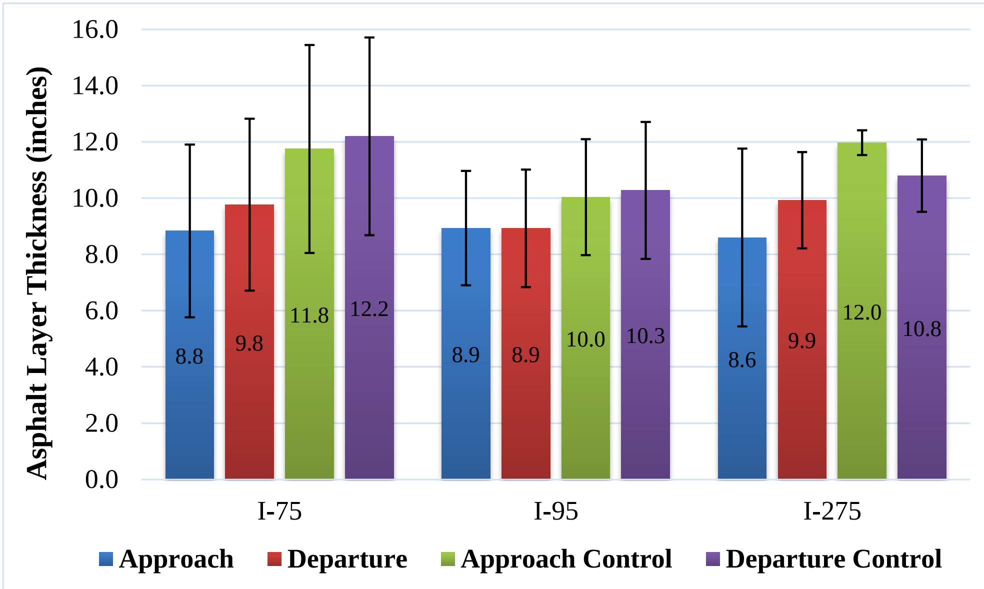


Figure 4-27 Comparison of asphalt layer thickness across routes

4.5 Analysis of Rutting and Smoothness Characteristics

The pavement condition analysis in the previous sections focused on the extent of distresses of bridge approach/departure asphalt pavements. In this section, the characteristics of rutting and smoothness (in terms of IRI) are further analyzed statistically to help determine the rehabilitation criteria for bridge approach/departure asphalt pavements and to evaluate the possible factors influencing pavement performance. Use of the 2014-2015 two-year condition data from FDOT SMO allows the analysis of distress progression over time.

In the two-year condition data, a total of 927 bridges with approach/departure asphalt pavements are available. Among these bridges, 44 bridges and 883 bridges are located on undivided and divided highways, respectively. The beginning mile post (BMP) and ending mile post (EMP) of a bridge on the left side or right side of a divided highway are shown in Figure 4-28. As shown in the figure, the mile posts of bridge approach are smaller than the mile posts of bridge departure on the right side of divided highways. However, on the left side of divided highways, the mile posts of bridge approach are greater than the mile posts of bridge departure. In order to distinguish the bridge approach pavement and departure pavement accurately, only 883 bridges (448 bridges are on the left side, 435 bridges are on the right side) located on divided highways are considered in the following data analysis.

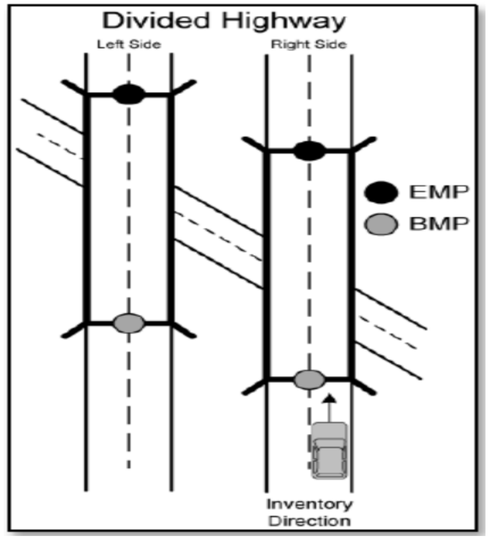


Figure 4-28 BMP and EMP of bridge on left/right side of divided highway (FDOT, 2016a)

The selected bridge approach/departure asphalt pavements were surveyed for a distance of 0.060 mi (about 317 ft) from each side of bridge structure. Among the total lengths of bridge approaches/departures, the survey lengths of the approach/departure slab and the approach/departure asphalt pavement are 0.006 mi (32 ft) and 0.054 mi (285 ft), respectively. Similar to the analysis in Section 4.3, the bridge approach/departure asphalt pavements are further divided into three 95 ft sections. Three sections located on the bridge approach pavement are named as Approach Section-1 (APP-1), Approach Section-2 (APP-2), and Approach Section-3 (APP-3), respectively. Three sections located on the bridge departure pavement are named as Departure Section-4 (DEP-4), Departure Section-5 (DEP-5), and Departure Section-6 (DEP-6), respectively, as illustrated in Figure 4-29.

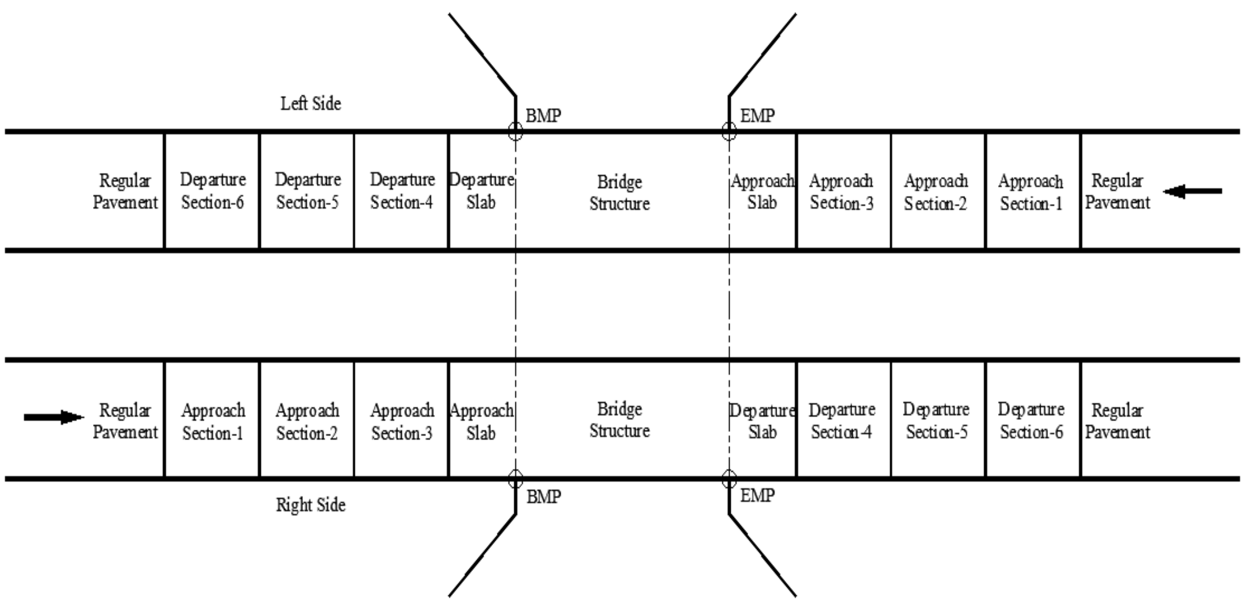


Figure 4-29 Schematic diagram of bridge approach/departure slab and pavement sections

Because IRI is highly correlated with riding number, riding number was not analyzed. Therefore, IRI and rut depth are two main indicators used to evaluate the performance of bridge approach/departure asphalt pavements. Since IRI is a function of any of the various forms of distress (i.e., rutting, cracking, pothole, etc.), it may be used to reflect the severity of pavement distress condition (Lin et al., 2003).

4.5.1 Comparative Analysis of IRI and Rut Depth on Different Pavement Sections

Because distresses may appear non-uniformly on the 285 ft long bridge approach pavement, the average IRI and rut depth on bridge approach/departure asphalt pavements and control sections were calculated. The comparison results of IRI and rut depth on different sections are shown in Figure 4-30 and Figure 4-31, respectively.

As shown in Figure 4-30, the average smoothness decreases when the distance between pavement section and bridge approach/departure slab decreases. Paired t-tests showed that the average IRI and IRI increment from 2014 to 2015 on bridge approach/departure asphalt pavements are significantly (at the 95% confidence level) greater than those on control sections, especially for Approach Section-3 (APP-3) and Departure Section-4 (DEP-4). The average IRI value on the bridge departure pavement is significantly larger than that on bridge approach pavement at the 95% confidence level. The IRI increment from 2014 to 2015 on the bridge departure section DEP-4 is significantly higher (at the 95% confidence level) than that on the bridge approach section APP-3. This indicates that the deterioration rate of bridge departure section DEP-4 is greater than that of the bridge approach section APP-3.

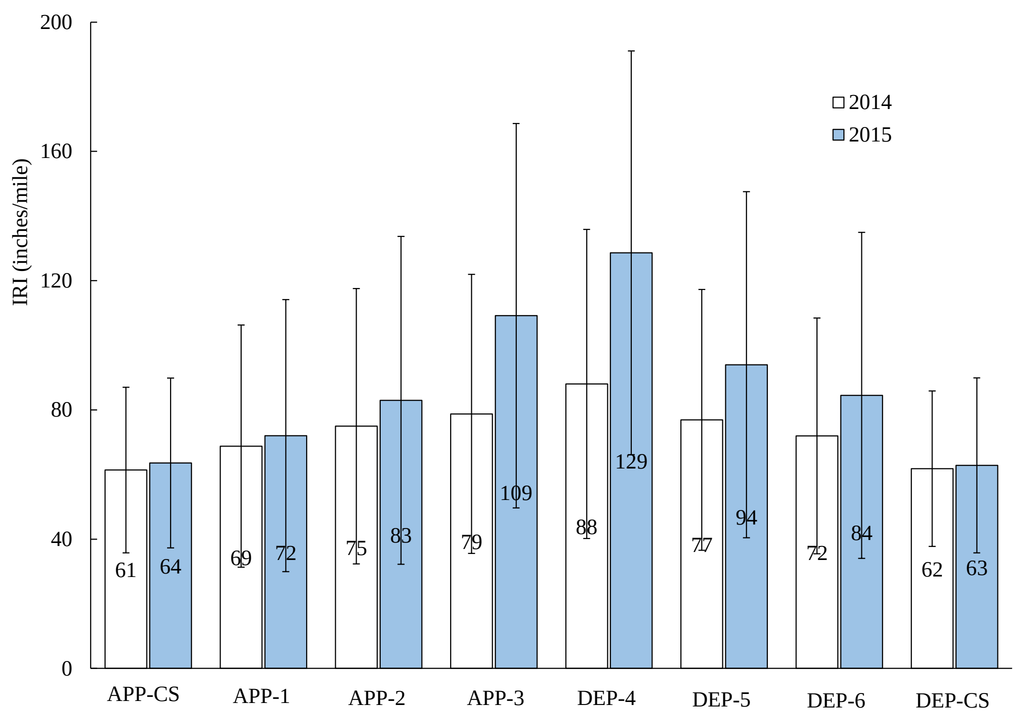


Figure 4-30 Average IRI on bridge approaches/departures and control section

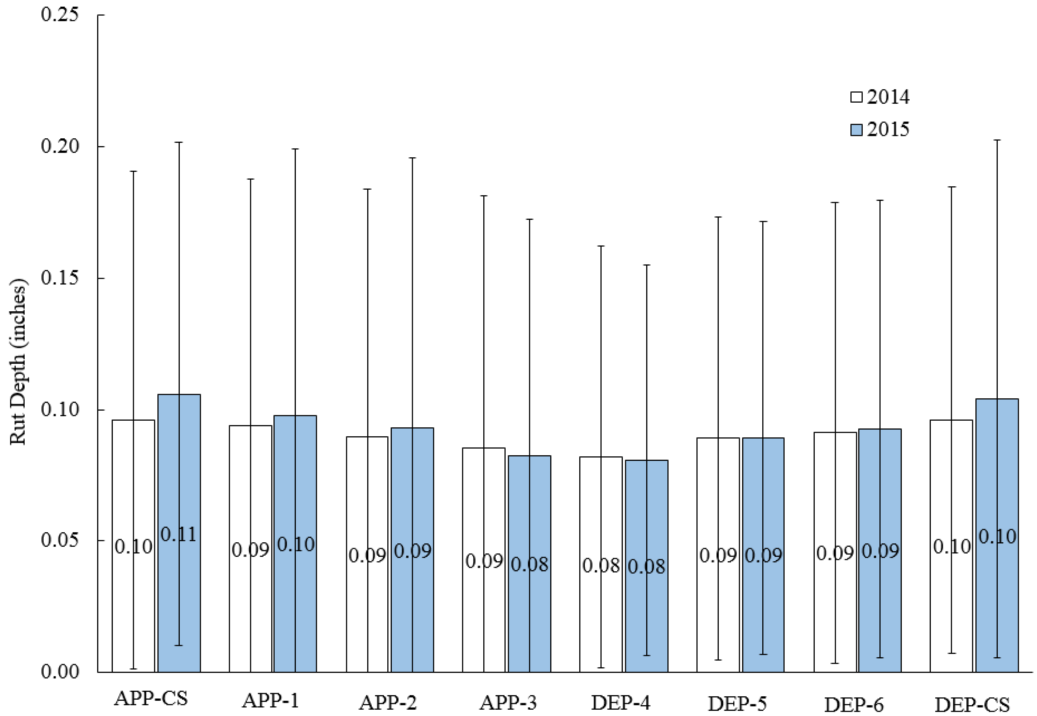


Figure 4-31 Average rut depth on bridge approaches/departures and control section

As can be seen from Figure 4-31, the average rut depth generally increases slightly with the increasing distance from bridge approach/departure slabs. Paired t-tests, however, revealed that the average rut depth and rut depth increment from 2014 to 2015 on control sections are not statistically different from those on bridge approach/departure asphalt pavements at the 95% confidence level.

4.5.2 Descriptive Statistical Analysis of IRI and Rut Depth on Different Pavement Sections

The distributions of average IRI on bridge Approach Section-3 (APP-3) and Departure Section-4 (DEP-4) (i.e., the two sections adjacent to the approach/departure slabs) are shown in Figure 4-32 and Figure 4-33, respectively. As can be seen from the two figures, the average IRI on APP-3 or DEP-4 of the 883 bridges approximately follows a log-normal distribution. The mode of distribution is about 90 in/mi for the average IRI on DEP-4, and only 50 in/mi for the average IRI on APP -3. For most bridges, the average IRI on APP-3 or DEP-4 is less than 200 in/mi.

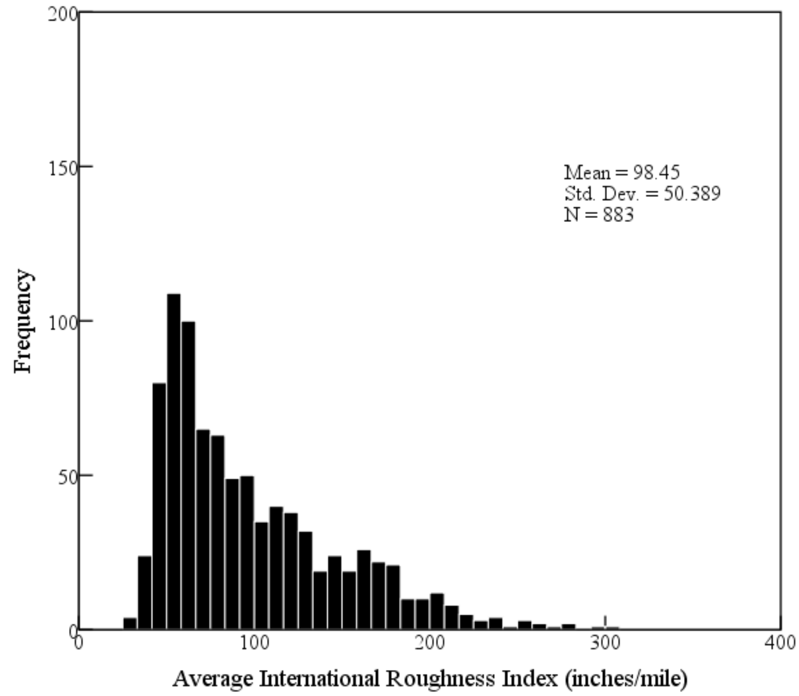


Figure 4-32 Distribution of average IRI on bridge Approach Section-3

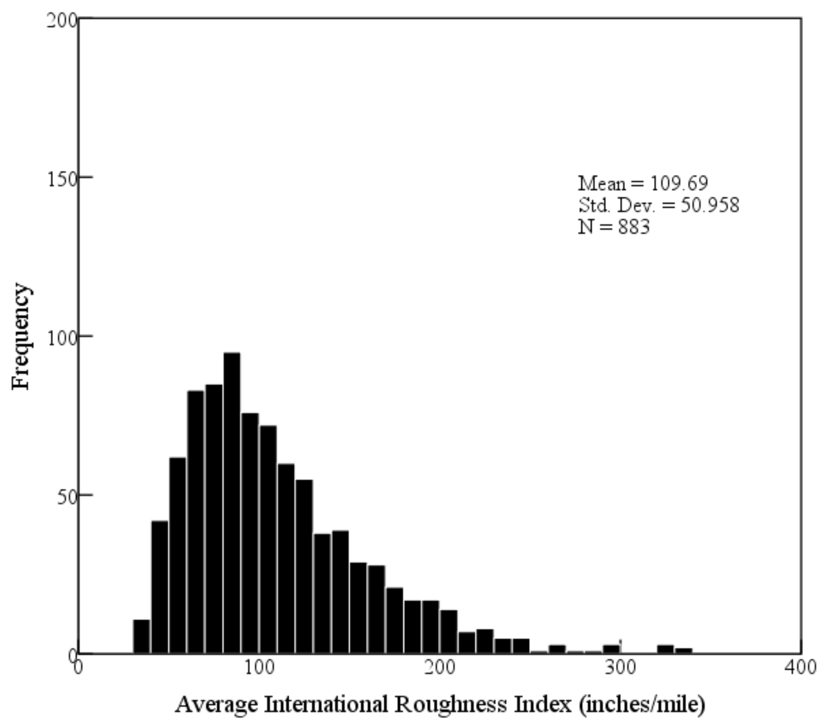


Figure 4-33 Distribution of average IRI on bridge Departure Section-4

The distributions of average rut depth on bridge Approach Section-1 (APP-1) and Departure Section-6 (DEP-6) (i.e., the two sections away from the approach/departure slabs) are shown in Figure 4-34 and Figure 4-35, respectively. As can be seen, the average rut depth on APP-1 or

DEP-4 of the 883 bridges seems to follow an exponential distribution. For most bridges, the average rut depth on APP-1 or DEP-4 is less than 0.25 in.

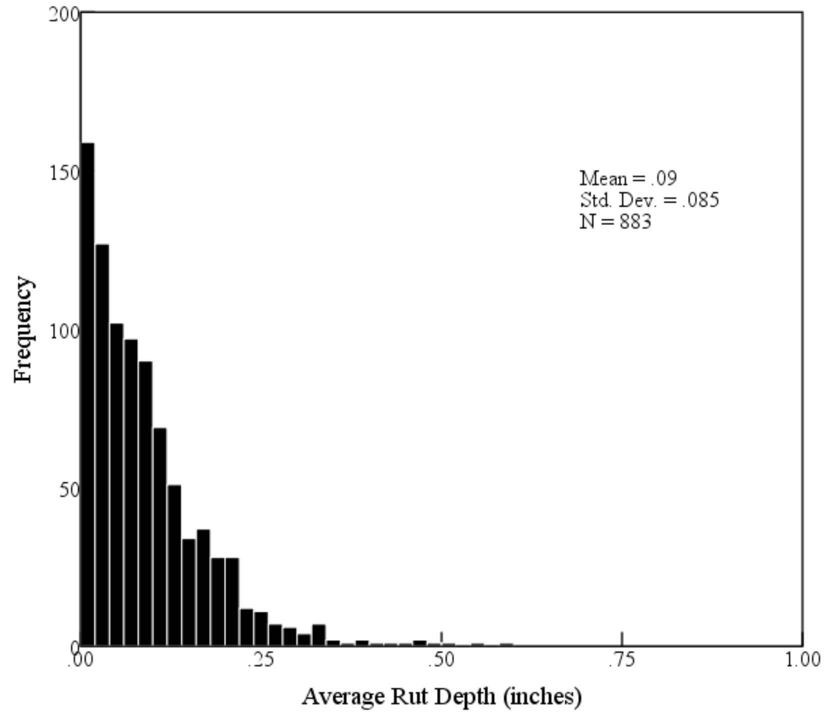


Figure 4-34 Distribution of average rut depth on bridge Approach Section-1

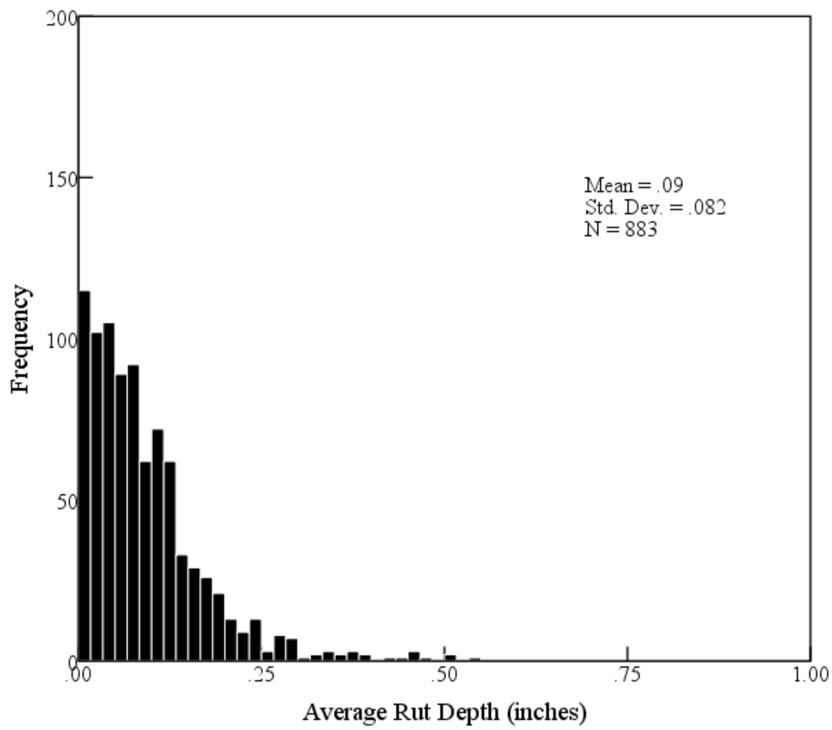


Figure 4-35 Distribution of average rut depth on bridge Departure Section-6

4.5.3 Multiple Regression Analysis of IRI and Rut Depth on Different Pavement Sections

For pavement management purpose, pavement performance models are needed for prediction of future pavement performance. In this section, effort is attempted to develop smoothness and rut depth models for bridge approach/departure asphalt pavements using regression analysis. For this purpose, relevant information was collected from various sources (mainly from FDOT SMO) and compiled together. The data set developed for the regression analysis was compiled from four major sources. The first source is FDOT pavement condition database, which contains smoothness and rut depth data for bridge approach pavements from 2014 to 2015. The second source is FDOT Roadway Characteristic Inventory (RCI) database, which contains comprehensive roadway information, such as traffic-related information and pavement structure information (e.g., base layer type, base layer thickness, surface layer type). The third source is FDOT pavement management reports, which contain information about recent maintenance year for each roadway section. The fourth source is Florida Automated Weather Network, which provides the weather information (e.g., maximum temperature, minimum temperature, average annual precipitation) for each county.

The two-year pavement condition data were selected based on the following principle: pavement condition (IRI and rut depth) in 2015 should not be better than that in 2014 if no maintenance or rehabilitation work was performed in 2014. It was noted that variability in time-series pavement performance data may occur due to a number of factors, such as variations in profiled paths, seasonal effects, and maintenance activities (Perera et al., 1998).

Based on the previous comparative analysis, it was found that smoothness is the lowest on approach/departure pavement sections closer to the approach/departure slabs (i.e., APP-3 and DEP-4 as defined in Figure 4-29), while rutting is most severe on approach/departure pavement sections away from the approach/departure slabs (i.e., APP-1 and DEP-6 as defined in Figure 4-29). Therefore, smoothness measured from APP-3 and DEP-4 was used to develop the pavement smoothness model, and rut depth measured from APP-1 and DEP-6 was used to develop the pavement rut depth model. It should be noted that although only two consecutive years' data are used for modeling, the developed models can be used to predict pavement performance (in terms of smoothness and rut depth) for a wide range of pavement ages. This is because the pavement sections included in the data set have various ages at the time of condition survey.

4.5.3.1 Bridge approach/departure asphalt pavement smoothness model

In this study, 423 bridge approach pavement sections and 408 bridge departure pavement sections were selected for smoothness analysis. The pavement smoothness models developed for bridge Approach Section-3 (APP-3) and Departure Section-4 (DEP-4) are shown in Equation (4-1) and Equation (4-2), respectively.

$$IRI_{APP3} = 1.1291 \times IRI_{APP0} + 1.2634 \times PaveAge + 1.1536 \times AADTT/1{,}000 \quad (4\text{-}1)$$

$$IRI_{DEP4} = 1.1126 \times IRI_{DEP0} + 1.8004 \times PaveAge + 1.6466 \times AADTT/1{,}000 \quad (4\text{-}2)$$

where, IRI_{APP3} is the IRI of APP-3 in a prediction year; IRI_{APP0} is the IRI of APP-3 in the previous year of the prediction year; $PaveAge$ is pavement age relative to the most recent maintenance or rehabilitation work; $AADTT$ is the average annual daily truck traffic (AADTT); IRI_{DEP4} is the IRI of DEP-4 in a prediction year, IRI_{DEP0} is the IRI of DEP-4 in the previous year of the prediction year. The independent variables included in the pavement smoothness models (i.e., initial smoothness, pavement age, and truck traffic volume) are all statistically significant at a confidence level of 95%. The adjusted R^2 values for the APP-3 and DEP-4 smoothness models, however, are not very high (0.56 and 0.39 respectively). This indicates that there are other unobserved factors that also influence bridge approach/departure pavements.

Based on the descriptive statistical analysis, the average AADTT for bridge approaches is about 8,000 trucks/day. The initial IRI is about 80 and 90 in/mi on the bridge approach section APP-3 and the bridge departure section DEP-4, respectively. Based on the average information of AADTT and initial IRI, the relationship between bridge approach/departure asphalt pavement smoothness and pavement age was developed, as shown in Figure 4-36.

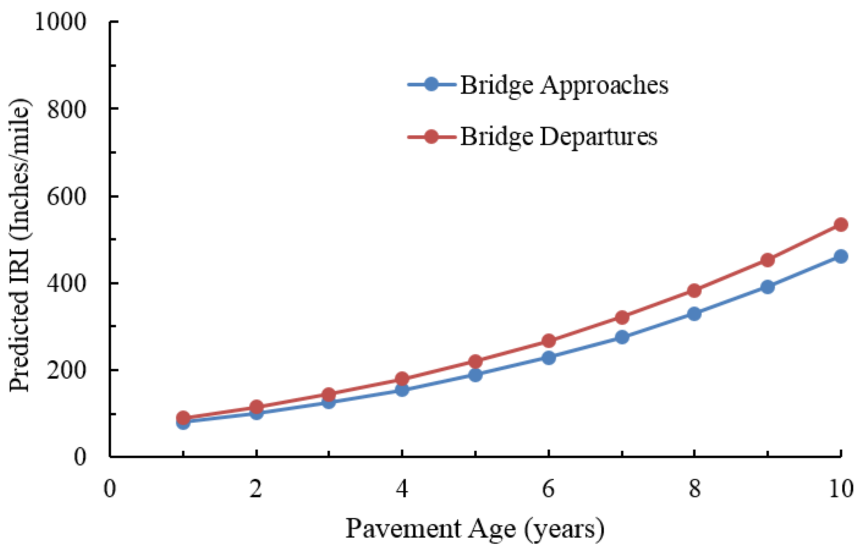


Figure 4-36 Relationship between bridge approach pavement IRI and pavement age

As shown in Figure 4-36, the increasing rate of IRI increases with pavement age. There is relatively small change of smoothness in the first few years of the age of a pavement, which is consistent with findings in the literature (Perera et al., 1998). When a bridge approach/departure asphalt pavement is initially smooth, the rate of decrease of smoothness with pavement age is smaller because of less dynamic load effect from vehicles. Rougher pavement surface would increase the dynamic loading of vehicles on pavement surface and accelerate the deterioration of pavement structure (Saleh et al., 2000). It can also be observed from Figure 4-36 that the average difference in IRI between bridge departure pavements and bridge approach pavements increases with pavement age.

4.5.3.2 Bridge approach/departure asphalt pavement rut depth model

In this study, 247 bridge approach asphalt pavement sections and 440 bridge departure asphalt pavement sections were used for rut depth analysis. The pavement rut depth models developed for bridge Approach Section-1 (APP-1) and Departure Section-6 (DEP-6) are shown in Equation (4-3) and Equation (4-4), respectively.

$$RUT_{APP1} = 1.1620 \times RUT_{APP0} + 0.0043 \times PaveAge \quad (4\text{-}3)$$
$$RUT_{DEP6} = 1.0802 \times RUT_{DEP0} + 0.0035 \times PaveAge + 0.0008 \times AADTT/1{,}000 \quad (4\text{-}4)$$

where, RUT_{APP1} is the rut depth of APP-1 in a prediction year; RUT_{APP0} is the rut depth of APP-1 in the previous year of the prediction year; $PaveAge$ is pavement age relative to the most recent maintenance or rehabilitation work; $AADTT$ is the average annual daily truck traffic; RUT_{DEP6} is the rut depth of DEP-6 in a prediction year; RUT_{DEP0} is the rut depth of DEP-6 in the previous year of the prediction year. The adjusted R^2 values for APP-1 and DEP-6 smoothness models are 0.70 and 0.75, respectively. The truck traffic volume is not a significant factor for bridge approach pavement rut depth.

Based on the descriptive statistical analysis, the initial rut depth is about 0.074 and 0.073 in on the bridge approach section APP-1 and bridge departure section DEP-6, respectively. Based on the average information of AADTT and initial rut depth, the relationship between bridge approach/departure asphalt pavement rut depth and pavement age was developed, as shown in Figure 4-37.

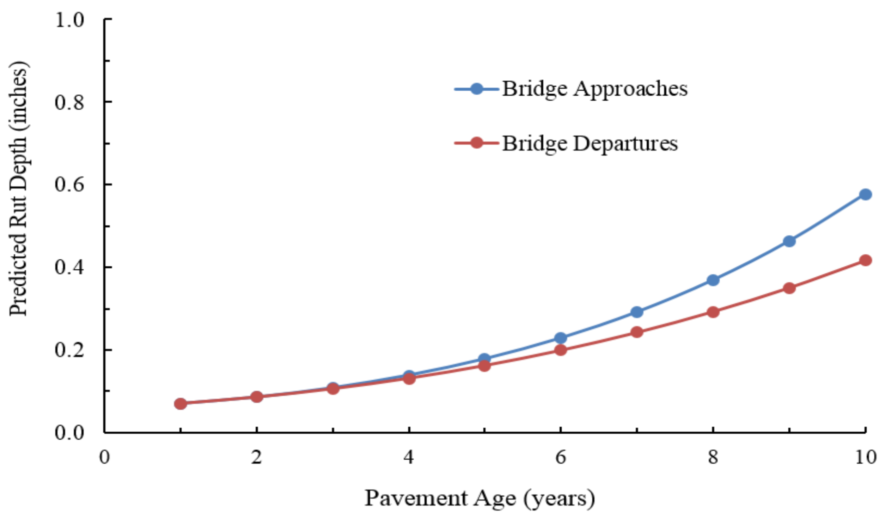


Figure 4-37 Relationship between bridge approach pavement rut depth and age

As can be seen from Figure 4-37, the increasing rate of rut depth also increases with pavement age. The average difference in rut depth between bridge approaches and bridge departures also increases with pavement age. The larger rut depth on bridge approaches is likely due to reduced vehicle speeds on uphill slopes.

4.5.4 Analysis of Contributing Factors of Bridge Approach/Departure Asphalt Pavement Smoothness

The smoothness models developed in the previous section for bridge approach/departure asphalt pavements do not include pavement structural variables such as layer thickness. This is primarily due to the lack of layer thickness data for bridge approach/departure asphalt pavements in the FDOT RCI database. As has been revealed, however, on some FDOT Interstate highways, the asphalt layer in bridge approach/departure asphalt pavements is significantly thinner than that in control sections (Moseley, 2009, 2012, 2013), which may lead to early deterioration of pavement smoothness. Pavement layer thickness, therefore, should be included in the statistical analysis. To this end, the GPR data used for asphalt layer thickness analysis in Section 4.4 are combined with all other data used for analysis in Section 4.5 and used to analyze the factors affecting bridge approach/departure asphalt pavement smoothness at a network level. Since the GPR test is only performed on a pavement section upon special request from district offices, the available GPR data do not cover all the bridge approach/departure asphalt pavements in Florida. Due to this limitation, only 73 bridges were identified, whose approach, departure, and control sections can be included in the analysis. A list of the 73 bridges is shown in Appendix E, among which 7, 31, 31, 2, and 2 bridges are located in Districts 1, 2, 4, 5, and 7, respectively. These bridges are on either Interstate Highway I-95 or Interstate Highway I-75.

The pavement smoothness data (i.e., IRI) collected in 2014 were used in the analysis. Table 4-13 shows the descriptive statistics of potential variables influencing pavement smoothness.

Table 4-13 Descriptive statistics of potential variables influencing pavement smoothness

Variable Description (Number of Observations: 73)	Mean Value	Standard Deviation	Minimum Value	Maximum Value
IRI of control section (in/mi)	72.277	19.502	38.631	141.826
IRI of bridge approach pavement (in/mi)	107.021	29.819	38.961	224.984
IRI of bridge departure pavement (in/mi)	117.461	33.381	54.474	216.654
Surface layer thickness of control section (in)	10.575	2.835	4.436	17.115
Surface layer thickness of bridge approach pavement (in)	8.528	2.635	2.330	14.910
Surface layer thickness of bridge departure pavement (in)	8.689	2.746	2.690	14.320
Total thickness of asphalt pavement layer and base layer on control section (in)	20.561	2.744	14.075	27.115
Friction course type indicator (1 if friction course of pavement surface layer is friction course 2 [FC-2], 0 otherwise)	0.151	0.360	0	1
Base layer thickness of control section (in)	9.986	0.589	9.000	13.000
Base layer type indicator (1 if type of base layer is limerock base [LR], 0 otherwise)	0.753	0.434	0	1
Thin base layer at bridge approach transition area (1 if thickness of bridge approach pavement base layer is less than 10 in, 0 otherwise)	0.096	0.296	0	1
Thin asphalt pavement at bridge departure transition area (1 if bridge departure pavement surface layer thickness is statistically less than corresponding control section surface layer thickness at a 95% confidence level, 0 otherwise)	0.644	0.482	0	1
Pavement age from the most recent pavement rehabilitation year (years)	8.301	3.353	2	13
Annual average daily traffic (AADT) (1,000 vehicles per day)	93.828	57.090	45.411	221.000
Annual average daily truck traffic (AADTT) (1,000 vehicles per day)	12.502	12.105	4.264	55.253
Heavy truck traffic volume indicator (1 if annual average daily truck traffic volume is more than 10,000 vehicles per day)	0.521	0.503	0	1
Higher speed limit indicator (1 if speed limit is greater than 65 mph, 0 otherwise)	0.795	0.407	0	1

Table 4-13 Descriptive statistics of potential variables influencing pavement smoothness (continued)

Variable Description (Number of Observations: 73)	Mean Value	Standard Deviation	Minimum Value	Maximum Value
Number of roadway lanes (1 if number of roadway lanes is four, 0 otherwise)	0.247	0.434	0	1
Length of bridge structure (ft)	261.613	282.547	79.200	1800.480
I-75 indicator (1 if Interstate highway is I-75, 0 otherwise)	0.411	0.495	0	1
I-95 indicator (1 if Interstate highway is I-95, 0 otherwise)	0.589	0.495	0	1

Since a bridge approach pavement and a bridge departure pavement share a series of unobserved factors (e.g., drainage design, subgrade condition.), pavement smoothness on roadway-bridge transition areas and control sections is best modeled by a system of interrelated equations. Therefore, a simultaneous-equation statistical model was applied to evaluate bridge approach/departure asphalt pavement smoothness, which can be written as (Greene, 2012)

$$IRI_C = \alpha_C + \beta_C X_C + \varepsilon_C \quad (4\text{-}1)$$
$$IRI_A = \alpha_A + \beta_A X_A + \psi_A IRI_C + \varepsilon_A \quad (4\text{-}2)$$
$$IRI_D = \alpha_D + \beta_D X_D + \psi_D IRI_C + \varepsilon_D \quad (4\text{-}3)$$

where IRI_C, IRI_A, and IRI_D are IRI of control section, bridge approach pavement, and bridge departure pavement, respectively; X_C, X_A, and X_D are vectors of pavement and roadway characteristics influencing control section smoothness, bridge approach pavement smoothness, and bridge departure pavement smoothness, respectively; α, β and ψ are estimable vectors, and ε_C, ε_A, and ε_D are error terms. To account for possible cross-equation correlation among the endogenous dependent variables (IRI_C) and equation disturbance terms (ε_C, ε_A, and ε_D), the three-stage least squares (3SLS) estimation method can be used to achieve estimable parameters (Greene, 2012). The estimated parameters for pavement smoothness models for bridge approach pavements and bridge departure pavements are shown in Table 4-14. It should be noted that these estimated parameters are based on the 2014 pavement condition data and the 73 bridge sites where the GPR data are available.

Table 4-14 Estimated parameters for bridge approach/departure pavement smoothness models

Variable Description	Estimated Parameter	t-Statistic
Dependent Variable: IRI of control section		
Constant	80.169	5.63
Pavement age	1.795	2.90
Pavement friction course type indicator	-23.873	-4.50
Heavy truck traffic indicator	16.232	3.99
Total thickness of asphalt pavement layer and base layer	-1.345	-2.05
Dependent Variable: IRI of Bridge Approach Pavement		
Constant	71.690	5.76
IRI of control section (endogenous variable)	0.456	2.75
Absolutely thin base layer at bridge approach transition area	24.988	2.32
Dependent Variable: IRI of Bridge Departure Pavement		
Constant	37.208	3.12

Table 4-14 Estimated parameters for bridge approach/departure pavement smoothness models (continued)

IRI of control section (endogenous variable)	0.984	6.28
Relatively thin asphalt pavement at bridge departure transition area	14.153	2.25
Number of Observations	73	
R-squared (IRI of Control section)	0.382	
R-squared (IRI of Bridge Approach Pavement)	0.146	
R-squared (IRI of Bridge Departure Pavement)	0.398	

As can be seen in Table 4-14, the bridge approach/departure asphalt pavement performance has a positive correlation with control section performance. Factors influencing control section smoothness include pavement age, pavement friction course type (e.g., FC-2 or FC-5), total thickness of pavement surface layer and base layer, heavy truck traffic indicator (AADTT > 10,000 vehicles per day). A bridge approach pavement whose base layer is thinner than its control section base layer is more likely to increase the average IRI by 25 in/mi. In addition, a bridge departure pavement whose asphalt layer is thinner than its control section is more likely to increase the average IRI by 14.2 in/mi.

The R-squared values for the estimated models are all low, indicating that a high proportion of the variance in the dependent variable (IRI) is not explained by the independent variables listed in Table 4-13. This is likely due to the limited sample size of pavement sections included in the statistical analysis, inherent high variance of pavement smoothness, and omission of some relevant variables (e.g., drainage quality and layer modulus) in the models due to lack of data.

4.6 Summary of FDOT Bridge Approach/Departure Asphalt Pavement Data Analysis

The conditions of bridge approach/departure asphalt pavements in the outer (truck) lane on FDOT Interstate highways were analyzed using crack rating from video log images and rut rating, IRI, and ride rating from high-resolution pavement condition survey data.

It was found that generally, bridge approach/departure asphalt pavements have more cracking and lower smoothness than control sections. The difference in rutting distress, however, is less significant than the differences in cracking and smoothness. There is no significant difference between approach pavements and departure pavements in terms of Crack Rating and Rut Rating. The departure pavements, however, are generally rougher than the approach pavements. Moreover, the smoothness of a bridge approach/departure asphalt pavement generally decreases as it gets closer to the approach/departure slab.

Among the over 1,000 Interstate highway bridges with approach/departure asphalt pavements, about 27% of bridges showed signs of cracking distress in their approach or departure pavements. About 20% of bridges have noticeable rutting in their approach or departure pavements. Among all the bridges whose control sections have good riding condition (i.e., IRI lower than 95 in/mi), there are about 30% of bridges showing worse riding condition (i.e., IRI greater than 95 in/mi) on their approach pavements, and about 50% of bridges showing worse riding conditions on their departure pavements.

Among the seven FDOT districts, District 4 had the highest number of bridges showing cracking distress in the approach/departure asphalt pavements, while District 3 had the lowest number. However, among the bridges showing cracking distress in approach/departure asphalt pavements, Districts 1, 5, and 7 had relatively worse pavement condition near bridges than other districts.

About 71 percent of the bridges analyzed in the study were on I-75, I-95, and I-10, but bridges showing distresses in approach/departure asphalt pavements were mainly on I-75 and I-95. About 34 of bridges on I-75 and 52% of bridges on I-95 showed distresses in approach/departure asphalt pavements.

Based on the GPR data for 113 bridges, it was found that the average asphalt layer thickness is significantly lower on bridge approaches or departures than on control sections, and the difference is most significant in Districts 2 and 5, and on I-75.

Based on the multiple regression analysis, both average IRI and average rut depth on bridge approach/departure asphalt pavements increase with pavement age. Due to the existence of interaction between traffic loading and pavement condition, the increase rates of IRI and rut depth also increase with pavement age. In addition, the difference between bridge approach pavement condition and bridge departure pavement condition becomes more significant with increasing pavement age.

CHAPTER 5 REHABILITATION CRITERIA FOR BRIDGE APPROACH/DEPARTURE ASPHALT PAVEMENTS

5.1 Proposed Pavement Rating System Based on Rutting and Smoothness

Based on the literature review in Chapter 2, it was found that differential settlement, approach-relative gradient, bridge approach index, and IRI have been proposed as performance indicators to determine maintenance and repair needs for bridge approach/departure pavements. However, the literature review and initial and follow-up questionnaire surveys did not reveal any rehabilitation criteria specifically for bridge approach/departure asphalt pavements.

Based on the analysis of Florida Interstate highway bridge approach/departure asphalt pavement data in Chapter 4, average rut depth and average IRI may be used to develop the bridge approach/departure asphalt pavement condition rating system because the rut and ride data are collected annually by the Pavement Condition Unit (PCU) of the FDOT SMO at a special resolution (every 0.001 mi) high enough to distinguish a bridge approach/departure asphalt pavement section.

Since the average rut depth would generally decrease while the average IRI would generally increase as the pavement section gets closer to the bridge structure, the average rut depth of bridge Approach Section-1 (APP-1) and bridge Departure Section-6 (DEP-6), as illustrated in Figure 4-29, and the average IRI of bridge Approach Section-3 (APP-3) and bridge Departure Section-4 (DEP-4) are preferred as the pavement condition indicators.

For the average rut depth, a threshold value of 0.5 in is also selected since this value is commonly used to define rutting failure of asphalt pavements. Following the Washington State's regular pavement condition rating system (Papagiannakis et al., 2009), this study proposes a similar rating system for bridge approach/departure asphalt pavements, as shown in Figure 5-1. In this rating system, if the average rut depth on the bridge Approach Section-1 (APP-1) or the bridge Departure Section-6 (DEP-6) exceed 0.5 in, the pavement condition is rated as "very poor". If the average rut depth is less than 0.5 in, the bridge approach/departure asphalt pavement condition will then be evaluated based on the average IRI of bridge Approach Section-3 (APP-3) or bridge Departure Section-4 (DEP-4). If the average IRI (on APP-3 or DEP-4) exceeds 220 in/mi (the value used in the Washington State's pavement condition rating system), the pavement condition is rated as "poor" or "very poor". M&R will be needed when the pavement condition is rated below "fair".

Using the proposed rating system, the bridge approach/departure asphalt pavements included in this study were rated based on their condition data averaged over the 2014-2015 period. The distributions of the ratings of bridge approach asphalt pavements and departure asphalt pavements are shown in Figure 5-2 and Figure 5-3, respectively. As can be seen, about 97% of the bridge approach/departure asphalt pavements are in good or fair condition, 2.4% of the bridge approach asphalt pavements and 3.8% of the bridge departure asphalt pavements are in poor or very poor condition.

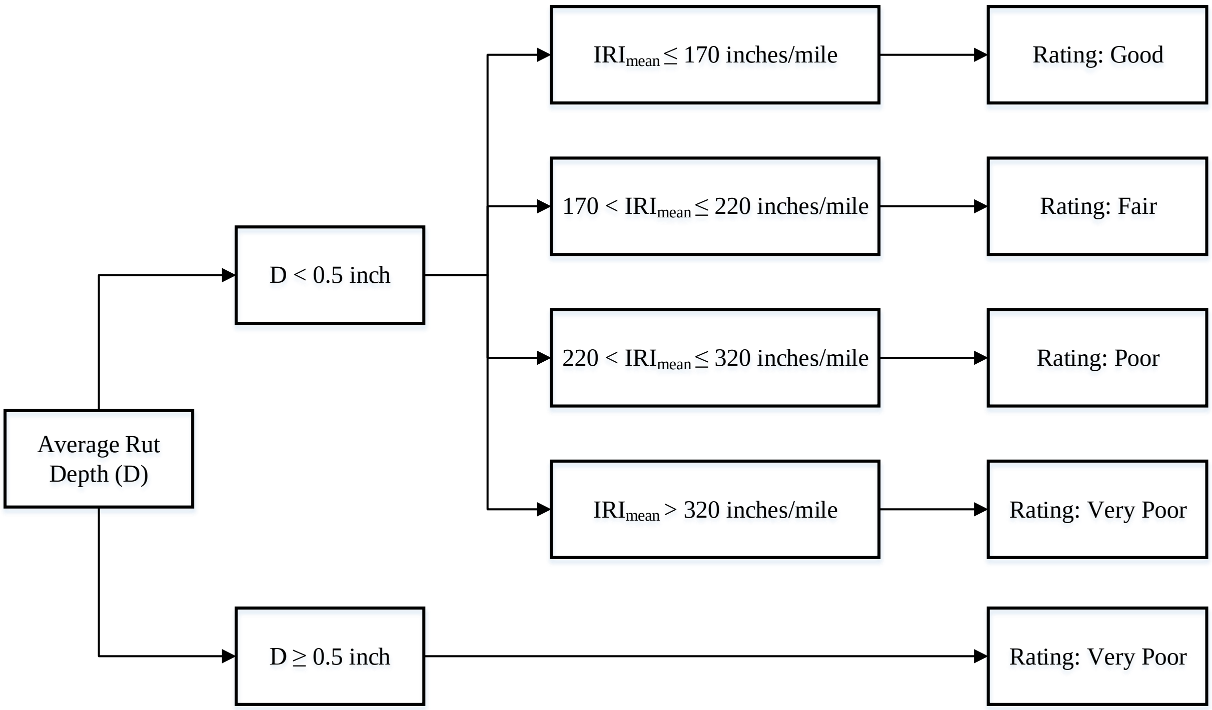


Figure 5-1 Proposed rating system for bridge approach/departure asphalt pavements

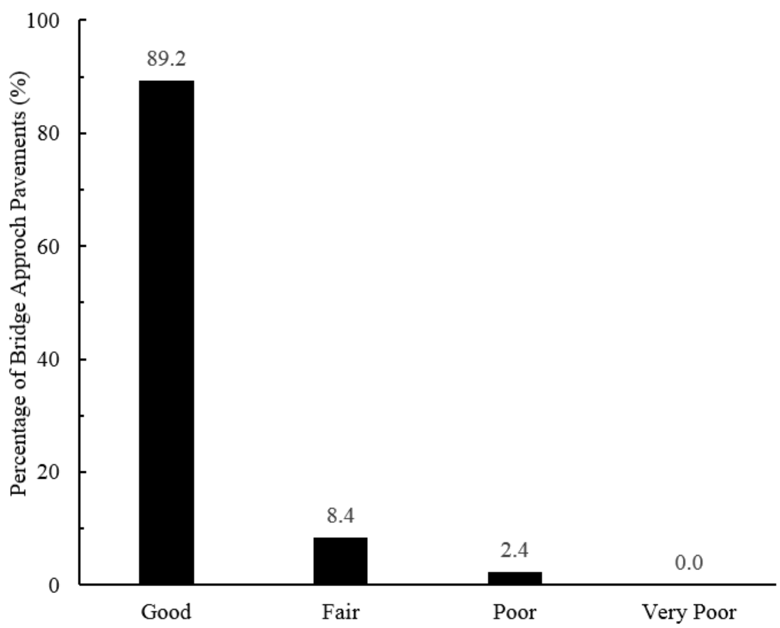


Figure 5-2 Distribution of bridge approach asphalt pavements by performance rating

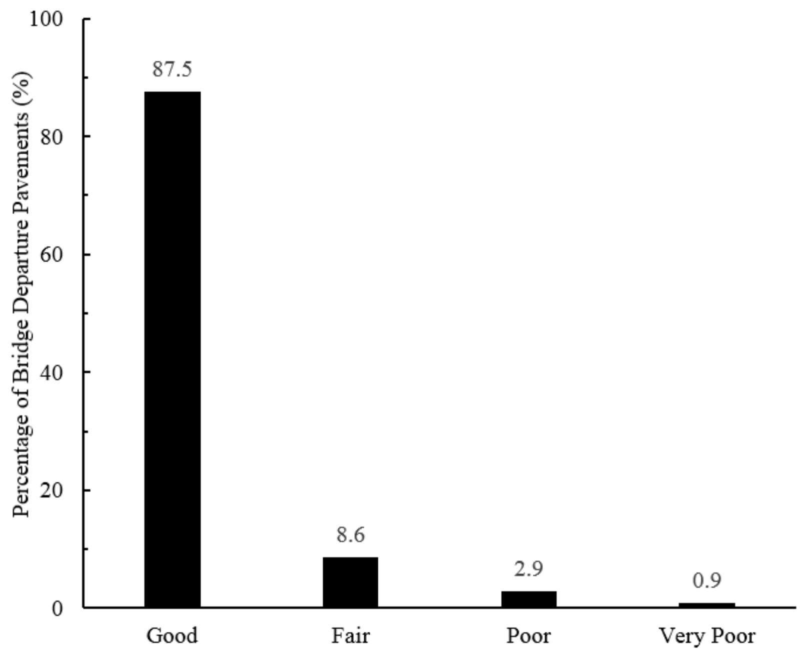


Figure 5-3 Distribution of bridge departure asphalt pavements by performance rating

The list of 2.4% (a total of 21) "poor or very poor" bridge approach asphalt pavements and 3.8% (a total of 34) "poor or very poor" bridge departure asphalt pavements is shown in Appendix F. The distributions of these "poor or very poor" bridge approach/departure asphalt pavements by district and highway route are shown in Figure 5-4 and Figure 5-5, respectively.

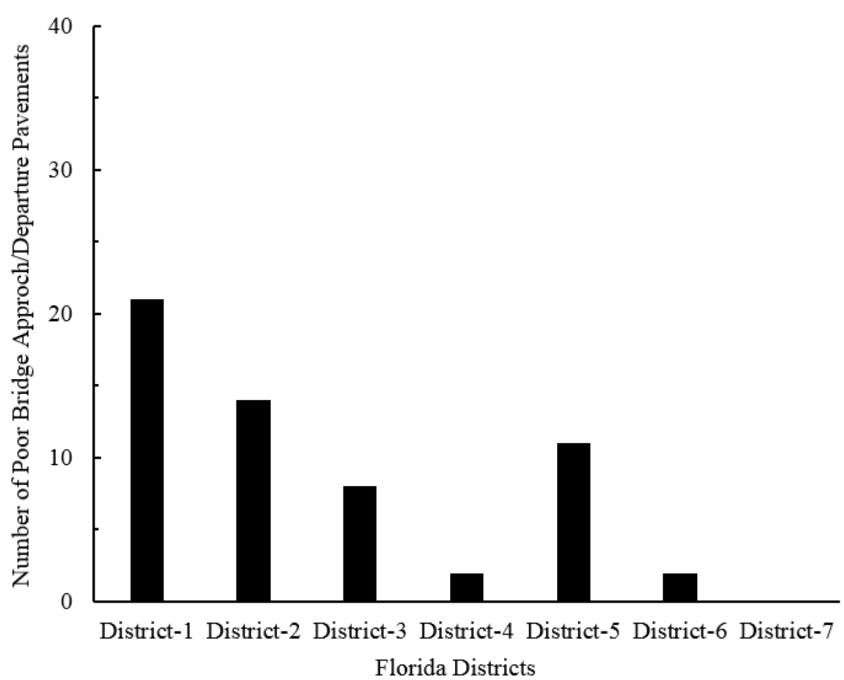


Figure 5-4 Distribution of poor/very poor bridge approach/departure pavements by district

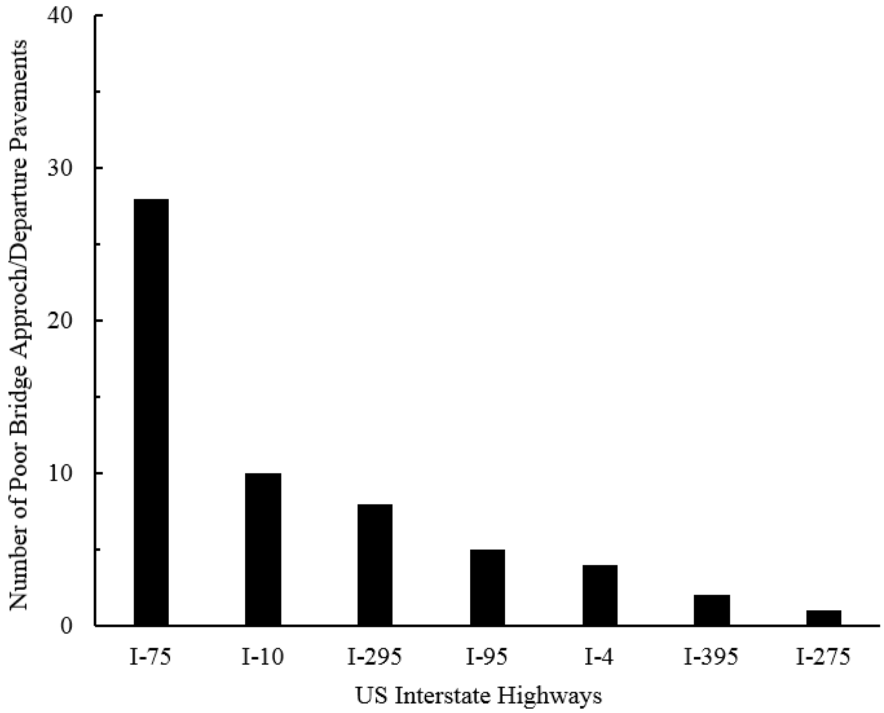


Figure 5-5 Distribution of poor/very poor bridge approach/departure pavements by route

As shown in the figures, most of the poor/very poor bridge approach/departure asphalt pavements are in Districts 1, 2, and 5, and on Interstate Highway 75 (I-75).

To determine the special rehabilitation needs of a bridge approach/departure asphalt pavement, its condition should be evaluated relative to its control section. For this purpose, a control section of the same length as the bridge approach/departure asphalt pavement should be selected. The pavement condition may be rated based on the IRI and rut depth (RD) data as collected during pavement condition survey. The proposed rating system based on IRI and RD is modified as follows.

The rating system for bridge approach/departure asphalt pavements based on IRI is shown in Table 5-1, explained as follows:

(1) If the mean value of IRI on a bridge approach pavement (IRI_{APP}) is not statistically greater than that on the control section (IRI_{CS}) at a 95% confidence level, the smoothness for bridge approach pavement is rated as “Good”. In this case, the bridge approach pavement would be rehabilitated along with the control section at the same time.
(2) If the mean value of IRI on a bridge approach pavement (IRI_{APP}) is statistically greater than that on the control section (IRI_{CS}) at a 95% confidence level, and it is less than 220 in/mi, the smoothness for the bridge approach pavement is rated as “Fair”.
(3) If the mean value of IRI on a bridge approach pavement (IRI_{APP}) is statistically greater than that on the control section (IRI_{CS}) at a 95% confidence level, and it is more than 220 in/mi, the smoothness for the bridge approach pavement is rated as “Poor”.

Table 5-1 Smoothness rating system for bridge approach/departure asphalt pavements

Smoothness Level	Criteria
Good	$IRI_{APP} \leq IRI_{CS}$
Fair	$IRI_{APP} > IRI_{CS}$ & $IRI_{APP} \leq 220$ in/mi
Poor	$IRI_{APP} > IRI_{CS}$ & $IRI_{APP} > 220$ in/mi

Similar to the rating system based on smoothness, the rating system for bridge approach/departure asphalt pavements based RD is shown in Table 5-2. In the table, RD_{APP} represents the mean value of RD on a bridge approach pavement and RD_{CS} represents the mean value of RD on a control section.

Table 5-2 Rutting rating system for bridge approach/departure asphalt pavements

Rutting Level	Criteria
Good	$RD_{APP} \leq RD_{CS}$
Fair	$RD_{APP} > RD_{CS}$ & $RD_{APP} < 1/2$ in
Poor	$RD_{APP} > RD_{CS}$ & $RD_{APP} \geq 1/2$ in

5.2 Proposed Pavement Rating System Based on Cracking

The FDOT annual pavement condition database contains a Crack Rating (CR) value for each pavement section. However, the pavement section is typically much longer than a bridge approach/departure asphalt pavement section. A bridge approach/departure asphalt pavement section is not independently defined and thus is typically included as a small portion of a roadway section. Information from the FDOT annual pavement condition database, therefore, cannot be used to evaluate the condition of bridge approach pavements.

CR is a composite indicator defined by FDOT to evaluate the type, severity, and quantity of cracking. It is on a scale of 10 (no cracking) to 0 (severest cracking) (FDOT, 2015). CR is calculated from visually assessed cracking condition following the procedure detailed in the FDOT survey handbook (FDOT, 2015). For bridge approach/departure asphalt pavements, extra effort may be needed from FDOT district offices to visually inspect their cracking condition. In this study, pavement video log images have been used to estimate the CR of each bridge approach pavement. Based on the findings as discussed in Chapter 4, a rating system for bridge approach/departure asphalt pavements based CR is proposed and presented in Table 5-3. In this table, CR_{APP} represents the mean value of CR on a bridge approach pavement and CR_{CS} represents the mean value of CR on a control section.

Table 5-3 Cracking rating system for bridge approach/departure asphalt pavements

Cracking Level	Criteria
Good	$CR_{APP} \geq CR_{CS}$
Fair	$CR_{APP} < CR_{CS}$ & $CR_{APP} > 7$
Poor	$CR_{APP} < CR_{CS}$ & $CR_{APP} \leq 7$

5.3 Rehabilitation Criteria for Bridge Approach/Departure Asphalt Pavements

Based on the proposed rating systems based on IRI, RD, and CR, a bridge approach/departure asphalt pavement that is rated as “Good” or “Fair” in all three systems may be maintained or rehabilitated along with its control section (i.e., adjacent regular pavement) at the same time. If any of the rating is below “Fair”, the bridge approach/departure asphalt pavement should be visually inspected and targeted for M&R. If either the RD or the CR rating is “Poor”, it should be considered for structural improvement.

Applying the proposed rating systems requires collection and analysis of pavement performance data following specific procedures, which is labor intensive and time consuming. If in a visual survey a bridge approach/departure asphalt pavement shows distresses that are obviously worse than its control section, it can be immediately identified as a deficient section in need of rehabilitation. Collection and analysis of performance data in terms of IRI, RD, and CR and the proposed rating systems, therefore, may not be needed.

CHAPTER 6 REHABILITATION GUIDELINES FOR BRIDGE APPROACH/DEPARTURE ASPHALT PAVEMENTS

Based on the work and findings presented in the previous chapters, the following procedure is recommended as general guidelines for condition evaluation and rehabilitation strategy selection for bridge approach/departure asphalt pavements:

(1) Pavement condition survey and evaluation;
(2) Identification of pavement distress causes and detailed data collection for poor pavement;
(3) Selection of rehabilitation techniques;
(4) Formation of rehabilitation strategies;
(5) Life-cycle cost analysis;
(6) Selection of rehabilitation strategy.

Details of each step of the proposed procedure are covered in the following sections, with an illustration example in Section 6.6.3.

6.1 Pavement Condition Survey and Evaluation

The purpose of pavement condition survey and evaluation is to assess the present condition of a bridge approach/departure asphalt pavement, to identify its key distress types, and to determine its rehabilitation needs. A field survey of pavement condition can be conducted following FDOT Flexible Pavement Condition Survey Handbook to accurately determine the types, quantities, severities, and locations of distresses present (FDOT, 2015).

6.1.1 Bridge Approach/Departure Asphalt Pavement Section

In the literature, bridge approaches are defined as the sections of pavement located immediately off the ends of a bridge, regardless of whether they are located on the approach or departure side of the bridge, and so "bridge approach pavement" is also used to refer to a "bridge departure pavement". Oregon Department of Transportation (ODOT) analyzes bridge approach pavements for a distance of 200 ft from the ends of the bridge (Oregon DOT, 2011). This is consistent with the findings from the analysis of two-year FDOT pavement condition data for each 0.001 mi (5.3 ft) highway section, in terms of rut rating, IRI, and ride rating. Generally, the difference in condition indices between a bridge approach/departure asphalt pavement and a control section diminishes when the bridge approach/departure asphalt pavement is located 200-300 ft away from bridge ends.

In Florida, to make a smooth transition from a regular asphalt pavement to a bridge concrete pavement, 30 ft concrete slabs are typically constructed at both ends of a bridge. Thus, as illustrated in Figure 1-1, a typical bridge approach/departure asphalt pavement section may be identified as a transition area from the ends of a bridge approach/departure slab. The length of the transition area may be determined based on changes in pavement surface condition or asphalt layer thickness. If no assisting information is available, a default length in the range of 200-300 ft may be chosen for the transition area. The average value of pavement condition data over these transition areas may be used to evaluate their pavement performance.

6.1.2 Pavement Condition Survey

The Pavement Condition Unit (PCU) of the FDOT SMO conducts annual surveys of the entire State highway system in terms of crack, ride, and rut measurements of pavements. For asphalt pavements, their annual conditions are evaluated and recorded in terms of average values of CR, Rut Rating, and Ride Rating (RR) for each roadway section. However, as explained in Section 5.2, information from the FDOT annual pavement condition database cannot be used for bridge approach/departure asphalt pavements due to their small section lengths.

Since the PCU collects the RD and IRI data using an inertial profiler for each 0.001 mi (5.3 ft) highway section, the original measurement files can be used for analysis for short pavement sections on bridge approaches/departures. Rut Rating and RR, as defined by FDOT, may be calculated from RD and IRI, respectively (FDOT, 2015). For CR, extra effort may be needed from FDOT district offices to visually inspect the cracking condition of bridge approach/departure asphalt pavements either in the field or using pavement video log images.

After the crack, ride, and rut data are obtained for a bridge approach/departure asphalt pavement, descriptive statistical analysis may be performed to evaluate the present condition and rehabilitation needs of the pavement. If visual survey reveals that a bridge approach/departure asphalt pavement has obviously worse distresses than its control section, it can be immediately identified as a deficient section in need of repair. Collection and analysis of performance data in terms of CR, RD (or Rut Rating), and IRI (or RR) may be skipped.

6.1.3 Pavement Condition Evaluation

The condition of a bridge approach/departure asphalt pavement may be evaluated relative to its control section using the rating systems proposed in Chapter 5. For this purpose, a control section of the same length as the bridge approach pavement should be selected.

6.2 Detailed Data Collection

If a bridge approach/departure asphalt pavement is rated as “Poor” in terms of smoothness, cracking, or rutting level, it should be considered in need of M&R. To identify the causes of pavement distresses and to develop appropriate rehabilitation strategies, more detailed data collection may be needed for the poor bridge approach pavement. Particularly, GPR test and material sampling and testing can be conducted in the detailed data collection process.

6.2.1 Data Collection and Identification of Pavement Distress Causes

Early fatigue cracking is typically associated with a weak base, a weak subgrade, or an inadequate asphalt pavement structure, which may be identified with a GPR test (Hall et al., 2001). The GPR test can collect information to estimate pavement layer thickness, joint deterioration, and moisture contents in the base, subbase, and subgrade layers. As illustrated in Figure 6-1, the presence and location of excessive moisture in subsurface layers of bridge approach pavement can be detected by a GPR survey (Holzschuher, 2015).

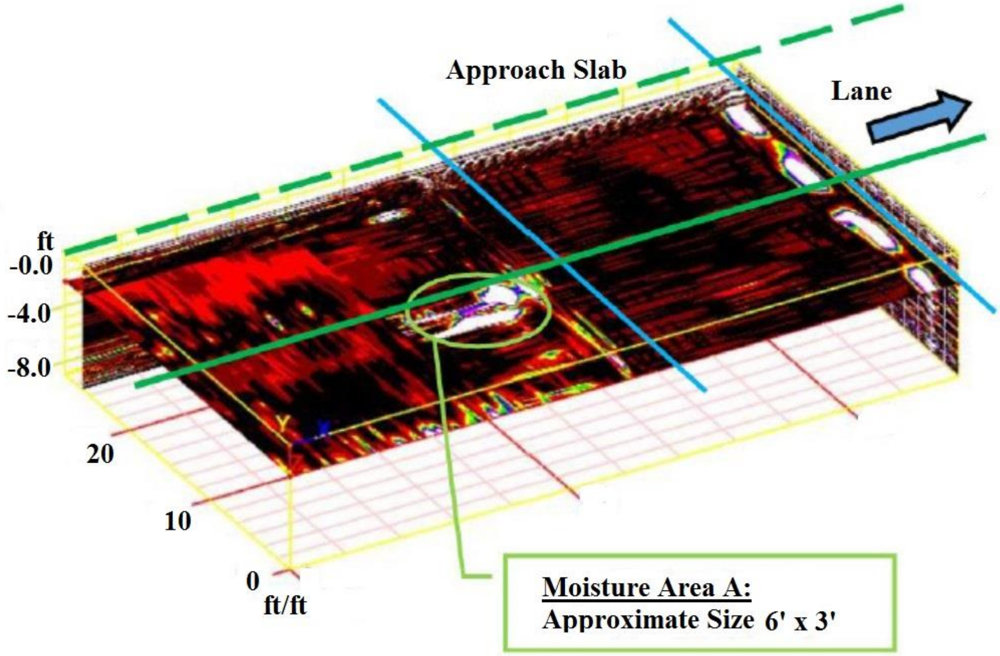


Figure 6-1 An example of GPR survey for bridge approach pavement (Bridge: 910097)

Rutting is typically caused by inadequate asphalt mixture design (e.g., use of a low-grade asphalt binder or excessively high binder content, use of rounded aggregates) or permanent deformation in the base, subbase or subgrade, which can be determined through material sampling and testing. Material samples can be taken by coring in the pavement, which requires temporary traffic control. Pavement cores can be measured and tested in the laboratory for needed information. Specifically, the bonding condition between layers, layer thickness, material type and characteristics (e.g., asphalt binder content, air-void content, aggregate gradation, moisture content), pavement deformation layer, and cracking depth may be determined. The bonding characteristics between layers can significantly affect the traffic and environmental stress and strain transfer efficiency from one layer to another (Rahman et al., 2017). The most commonly used test for bonding characteristics is direct shear test. For pavements whose contributing causes of distresses are below the pavement structure, a more comprehensive geotechnical investigation may be needed. The FDOT Soil and Foundations Handbook may be referred to for this purpose (FDOT, 2018).

As one example shown in Figure 6-2, the layer thickness and material type for bridge approach pavement sections are identified through materials sampling and testing (Prakash and Moseley, 2009). The material types shown in Figure 6-2 include friction course 5 (FC-5), 12.5-mm Superpave fine graded (SP2F), asphalt rubber membrane interlaced (ARMI), Type S asphaltic concrete, Type 1 asphaltic concrete, and asphalt binder course (BINDER).

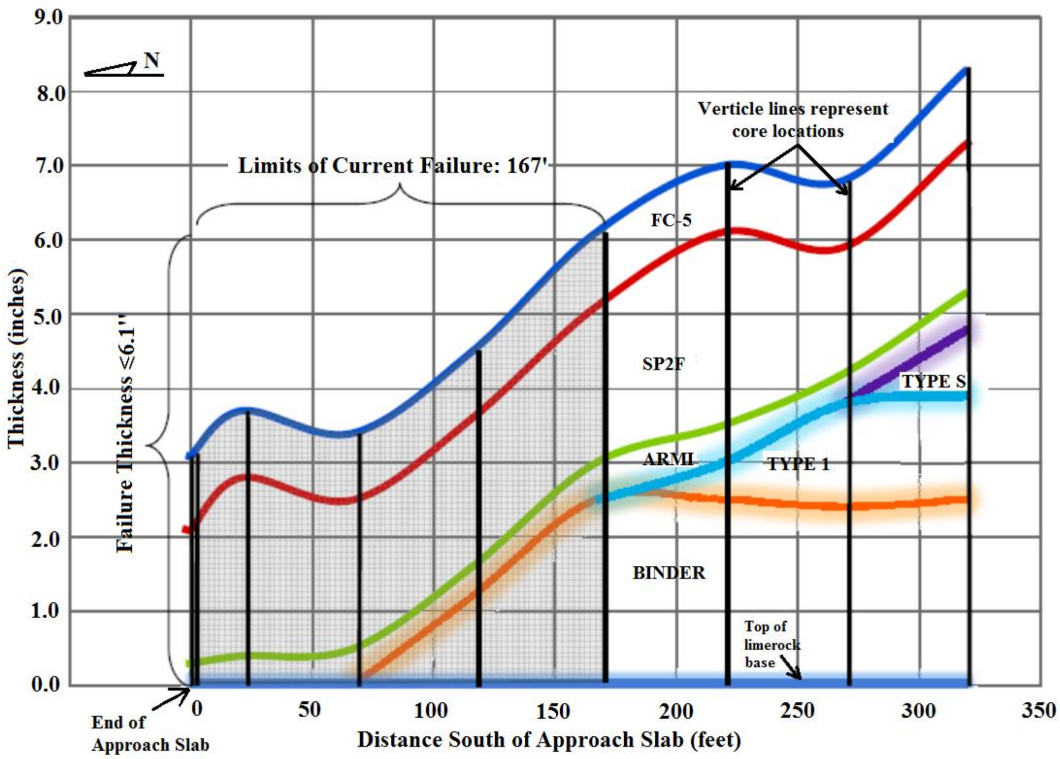


Figure 6-2 Materials sampling and testing results for one bridge approach pavement (Bridge: 260069)

As revealed in the literature review and questionnaire surveys, poor drainage features around bridge abutments may cause premature failure of a bridge approach pavement. If the GPR test and/or material sampling and testing reveal an excessively higher moisture content in the base, subbase, or subgrade layer of a bridge approach pavement compared to that of a control section, the drainage design and condition of the bridge approach pavement should be evaluated. Design and as-built information for the bridge approach pavement section should be collected to identify the designed drainage features such as edge-drains and outlets and/or a permeable base layer. Current conditions of these drainage features should be evaluated, including visual assessment of the clogging condition of edge-drains, measurement of the permeability of a permeable base layer, estimation and comparison of moisture inflow and capacity of a subsurface layer (Wyatt and Macari, 2000).

6.2.2 Other Sources of Relevant Information

Some relevant information for a bridge approach pavement may be collected from available data sources. For example, the FDOT RCI database contains information of bridge number, speed limit, number of lanes, widths of lanes, cross slope, predominant subgrade soil type, base layer type, base layer thickness, AADT, and AADTT (FDOT, 2016a). Pavement age since the recent rehabilitation year for each roadway section can be calculated from FDOT pavement management reports.

6.3 Selection of Rehabilitation Techniques

Once the need for repair and the types and potential causes of distresses are identified for a bridge approach/departure asphalt pavement, candidate rehabilitation techniques need to be selected. The repair techniques for bridge approach/departure asphalt pavements found from the literature review and questionnaire surveys, as discussed in Section 2.4, Section 3.4, and Section 3.5, mainly include patching, milling and inlay, and reconstruction. Additionally, rehabilitation techniques for regular asphalt pavements may also be of reference value. Therefore, they are summarized below.

6.3.1 Rehabilitation Techniques for Regular Asphalt Pavements

Literature review shows that rehabilitation techniques for regular asphalt pavements may include asphalt patching, cold milling, hot in-place recycling, cold in-place recycling, and asphalt overlay (Hall et al., 2001). If the causes of pavement distresses cannot be addressed by the above rehabilitation techniques, reconstruction should be considered.

Asphalt patching is placing new asphalt mixtures in an area of localized distresses. The original deteriorated pavement materials in the localized distress area need to be removed before asphalt patching. Asphalt patching may be full depth (down to the subgrade or an intact subbase layer) or partial depth (asphalt surface only), depending on the extent of the distress.

Cold milling is the removal of a portion depth of an asphalt concrete surface, using a cold milling machine. It is often done across the entire width of a traffic lane and is typically followed by an asphalt overlay. Cold milling cannot completely correct problems that extend throughout the full thickness of the asphalt concrete layer. Complete removal should be considered for an asphalt concrete layer with a serious material problem such as stripping or instability.

Hot in-place recycling (HIR) is the on-site rejuvenation of aged asphalt concrete material. It can be done with or without a subsequent asphalt overlay. HIR only improves the existing asphalt concrete layer to the depth which is recycled.

Cold in-place recycling (CIR) is the on-site reutilization of the asphalt concrete layer and the granular layers through a process without heat being added. CIR can be partial depth, which recycles the asphalt concrete layer to a depth of 3 to 4 in, or full depth, which involves the recycling of the asphalt concrete layer and the unbound granular layers (Hall et al., 2001). The full depth CIR is also known as full-depth reclamation (FDR). In the FDR, the asphalt concrete layer and a predetermined portion of the underlying materials are uniformly pulverized and blended together with asphalt emulsion or foamed asphalt to produce a homogeneous stabilized base course. CIR is typically done with a subsequent asphalt overlay. FDR has been successfully conducted on Interstate pavements (Hall et al., 2001). In-place recycling needs a road reclaimer or a series of equipment that can pulverize existing pavement materials, add and mix recycling agent, and place mixed materials on the roadway.

Asphalt overlay is the placement of a new asphalt concrete layer over an existing pavement structure. A functional overlay is mainly used for pavements with only functional deficiencies, such as excessive roughness, poor surface friction, bleeding, and raveling. A structural overlay can not only correct functional deficiencies but also increase the pavement structural capacity.

Pavement reconstruction is construction of a new pavement structure which involves complete removal and replacement of an existing pavement structure down to the subgrade.

6.3.2 Rehabilitation Techniques for Regular Asphalt Pavements with Vertical Alignment Constraint

As discussed in Section 3.3, a survey was conducted to collect information from other state DOTs regarding their rehabilitation techniques for structurally deficient asphalt pavements under the constraint that the vertical alignment of the roadway cannot be changed. The received responses include partial or full depth patching, milling and inlay of various depths, milling and functional or structural overlay, full-depth reclamation, and reconstruction with various service lives.

6.3.3 Discussion of Rehabilitation Techniques for Bridge Approach/Departure Asphalt Pavements

As shown in Section 3.5, the current FDOT rehabilitation practices for bridge approach/departure asphalt pavements include patching and crack sealing for short-term maintenance and repair, milling and inlay (including deep milling into the base layer) and full-depth reconstruction for long-term rehabilitation. Cold or hot in-place recycling has not been used as a rehabilitation practice for bridge approach/departure asphalt pavements. Due to its added benefits of material conservation and short construction periods, in-place recycling, particularly full-depth reclamation, may be considered in the selection of rehabilitation techniques for bridge approach/departure asphalt pavements.

6.4 Formation of Rehabilitation Strategies

A rehabilitation strategy is a combination of individual rehabilitation techniques that are identified in the previous section. The formation of each rehabilitation strategy alternative for bridge approach/departure asphalt pavements should not only address identified pavement distresses but also maintain the original longitudinal pavement profile. The objective of formation of rehabilitation strategies is to develop them with sufficient details so that their costs can be estimated and compared over the expected service life of the pavement.

6.4.1 Combining Rehabilitation Techniques into Strategies

To improve the structural capacity of a distressed bridge approach pavement, milling and inlay or reconstruction may be chosen as one rehabilitation technique in the rehabilitation strategy. Hot or cold in-place recycling, including full-depth reclamation, followed by asphalt overlay may also be included as one rehabilitation technique. If localized distresses exist to a base layer, additional repairs (e.g., chemical grouting, full-depth patching) may be performed prior to milling and inlay. If drainage deficiency exists, a drainage improvement option may be considered with asphalt inlay, such as repair or installation of edge-drains or a permeable base layer. If reconstruction is chosen, a completely new drainage system may be designed and included in the strategy.

6.4.2 Developing Detailed Rehabilitation Strategies

A detailed rehabilitation strategy is a sufficiently explicit description of the proposed work to be implemented for asphalt pavement distresses (Hall et al., 2001). To minimize the M&R frequency of a bridge approach/departure asphalt pavement, its remaining service life needs to be extended by increasing its structural capacity and serviceability. Then, a modified structural deficiency approach can be used to conduct the structural design of asphalt inlay or reconstruction for bridge approach/departure asphalt pavements.

6.4.2.1 Milling and asphalt inlay design for bridge approach/departure asphalt pavements
The specific milling and asphalt inlay design procedure for bridge approach/departure asphalt pavements consists of calculation of required structural number (SN_R), determination of milling depth and inlay thickness, asphalt material type selection, and thickness design. To maintain the original pavement profile, the inlay thickness should equal the milling depth.

The required structural number (SN_R) is a weighted thickness representing the required strength of the pavement structure, which can be calculated according to the AASHTO pavement design guide published in 1993 (AASHTO, 1993). The AASHTO design equation for calculating SN_R of an asphalt pavement is illustrated as follows:

$$log_{10}ESAL_D = Z_R S_O + 9.36 log_{10}(SN_R + 1) - 0.20 + log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)/(0.40 + 1094/(SN_R + 1)^{5.19}) + 2.32 log_{10}(M_R) - 8.07 \quad (6\text{-}1)$$

where, $ESAL_D$ is the accumulated 18-kip equivalent single axle loads (ESALs) predicted over the design period; SN_R is the structural number required in inch; Z_R is the standard normal deviate associated with the corresponding reliability value (%R); S_O is typically set as 0.45 used in the design calculations to account for variability in traffic load predictions and construction; ΔPSI is the difference between the initial serviceability ($P_I = 4.2$) and terminal serviceability ($P_T = 2.5$); M_R is resilient modulus of the roadbed soil which can be obtained from FDOT District Materials Offices (DMOs).

Because the reliability of rehabilitation ranges from 95% to 99% for Interstate highway pavements in Florida, the standard normal deviation Z_R can be set as -2.327 (at 99% reliability level) for bridge approach/departure asphalt pavements on the Interstate highways. The specific value of SN_R at different combinations of traffic loads and resilient modulus can be found from Appendix A of FDOT Flexible Pavement Design Manual (FPDM) (FDOT, 2016b).

To determine the milling depth and inlay thickness, the existing structural number (SN_E) needs to be evaluated with reduced layer coefficient values. FDOT FPDM includes recommended reduced layer coefficient values for different layer materials under various pavement condition. (FDOT, 2016b). These recommended values are for regular asphalt pavements. At current stage, with no further information, these values may be used for the bridge approach pavements, as summarized in Table 6-1 (FDOT, 2016b). The bridge approach/departure asphalt pavement condition determined previously based on smoothness, cracking, or rutting may be used to select a reduced layer coefficient value from Table 6-1 for a layer material.

Granular base, subbase, and stabilization, if present in the pavement structure, are assumed to remain full strength and are not reduced in the SN_E calculations. As stated in the FDOT FPDM (FDOT, 2016b), the inlay structural number should be greater than the difference between the SN_R and the SN_E after milling. In addition, to ensure that the vertical alignment of a bridge approach/departure asphalt pavement is not changed, the milling depth should be the same as the inlay thickness. The final structural number of a bridge approach/departure asphalt pavement after milling and inlay would increase with the milling depth.

Table 6-1 Reduced layer coefficients under different pavement conditions

Layer (with material type)	Original Design	Pavement Condition		
		Good	Fair	Poor
Friction Course, FC-5	0.00	0.00	0.00	0.00
Structural Course, SP-12.5	0.44	0.34	0.25	0.15
Structural Course, SP-19.0	0.44	0.34	0.25	0.15
Base Course, LR	0.18	0.18	0.18	0.18
Base Course, Type B-12.5	0.30	0.25	0.20	0.15
Subbase Course, LR	0.16	0.16	0.16	0.16
Stabilized Subgrade, LBR 40	0.08	0.08	0.08	0.08

The detailed procedure of determining the milling and inlay thickness is illustrated below.

1. Suppose that the entire existing asphalt pavement layer (i.e., the red bold line in Figure 6-3[a]) is milled and inlayed with a new structural course and a new friction course. The new structural number SN_N is calculated as:

   $$SN_N = 0.44D_1 + \sum_{i=2}^{4} a_i D_i \quad (6\text{-}2)$$

   where, 0.44 is the layer coefficient per inch for the new structural course; $a_i (i = 1, 2, 3, 4)$ is the reduced layer coefficient of the structural course, the base layer, the subbase layer, or the subgrade layer; $D_i (i = 1, 2, 3, 4)$ is the layer thickness in inch of the structural course, the base layer, the subbase layer, or the subgrade layer.

2. Compare values of the SN_R and the SN_N, and redesign the structural number SN_D.

   a. If $SN_R > SN_N$, as shown in Figure 6-3(b), a portion of the base layer needs to be milled to provide enough thickness for structural asphalt pavement resurfacing. The minimum milling depth of the base layer (d_2) can be determined from the following inequality:

   $$SN_D = (0.44 - a_2)d_2 + SN_N > SN_R \quad (6\text{-}3)$$

b. Then, the final milling depth is the total thickness of the existing asphalt pavement layer (e.g., friction course, structural course) plus the milling depth of the base layer (d_2). If $SN_R \leq SN_N$, as shown in Figure 6-3(c), the minimum milling depth of structural course layer (d_1) can be determined from the following inequality:

$$SN_D = 0.44d_1 + a_1(D_1 - d_1) + \sum_{i=2}^{4} a_i D_i > SN_R \qquad (6\text{-}4)$$

Then, the milling depth is the total thickness of friction course plus the milling depth of the structural course layer (d_1).

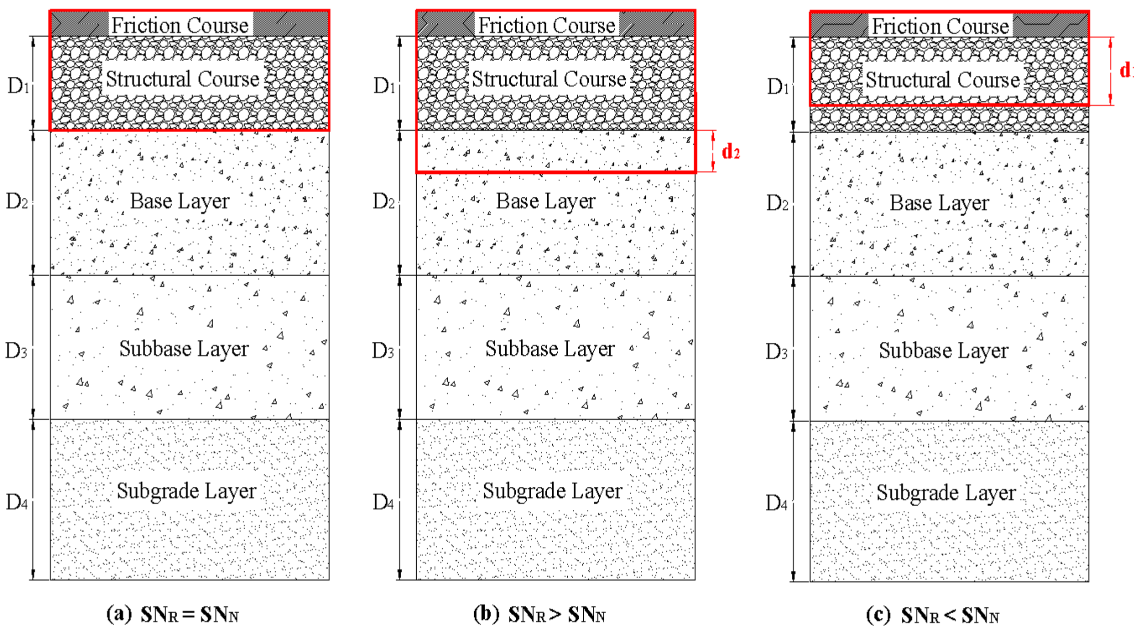


Figure 6-3 Schematic diagram of milling depth design

3. Check whether the milling depth is enough to remove the cracked asphalt pavement and rut susceptible mixes. If it is not enough, the milling depth should increase or additional repairs (e.g., full depth patching, crack sealing) should be implemented prior to inlay operation. In addition, an asphalt membrane interlayer (AMI) or a geotextile may be placed beneath the inlay to relief stress concentration at the tip of an existing crack below the inlay and to delay the crack propagation through the new inlay. Nam et al. proved that increasing the milling depth followed by geotextile is a most effective mitigation method for reflective cracking (Nam et al., 2014).

Once the total inlay thickness is determined, asphalt material type and thickness can be determined according to FDOT FPDM (FDOT, 2016b). For example, the asphalt concrete layer includes a friction course and a structural course. A friction course FC-5 is typically placed on Florida Interstate highways with a thickness of 0.75 in. The minimum thickness for the structural course on Interstate highways is 4 in. The structural course thickness is always designed to the nearest 1/2 in. The minimum layer thicknesses of SP-12.5 and SP-19.0 are 1-1/2 in and 2 in, respectively. The maximum layer thicknesses of SP-12.5 and SP-19.0 are 2-1/2 in and 4 in, respectively (FDOT, 2016b).

6.4.2.2 In-place recycling design for bridge approach/departure asphalt pavements

The modified structural deficiency approach may also be followed to design bridge approach/departure asphalt pavements rehabilitated with CIR or HIR. The structural layer coefficient (SLC), however, has to be determined for the recycled asphalt layer or the recycled base layer. FDOT's Materials Manual may be followed for this purpose, but it may take several years to determine the SLC for new materials. Information available in the literature may be used to accelerate this process (Hiltunen, 2014).

6.4.2.3 Reconstruction design for bridge approach/departure asphalt pavements

The reconstruction design of bridge approach/departure asphalt pavements may follow the same procedure of reconstruction design for regular asphalt pavements, with the additional constraint that the original pavement profile should not be changed.

Specifically, the reconstruction design of bridge approach/departure asphalt pavements consists of calculation of required structural number, determination of base group, and asphalt materials selection and thickness design. The required structural number for reconstruction can be calculated using the AASHTO flexible pavement design equation (5-1). The typical base group of bridge approach pavements on Interstate highways in Florida is base group 9 (10 in LR base), which is also a minimum base group for Interstate highway pavements. If the structural number for a reconstructed asphalt pavement (SN_N) with 10 in LR base is less than the required structural number, the granular base needs to be changed to an asphalt treated base. For example, if a 10 in LR base is replaced with a 6 in asphalt treated base (Type B-12.5), 4 in more asphalt structural course can be paved to increase the structural number. When the base group is determined, asphalt materials selection and thickness design can be conducted following the FDOT FPDM (FDOT, 2016b).

6.4.3 Summary

For a bridge approach/departure asphalt pavement, several rehabilitation strategies may be formed. A rehabilitation strategy is a combination of individual rehabilitation techniques that can not only address identified pavement distresses but also maintain the original longitudinal pavement profile. To improve pavement structural capacity, milling and inlay, in-place recycling, or reconstruction should be chosen as one rehabilitation technique in the rehabilitation strategy.

6.5 Life-cycle Cost Analysis

With a few rehabilitation strategy alternatives formed for a bridge approach/departure asphalt pavement, a life-cycle cost analysis (LCCA) may be performed to calculate and compare the costs of these alternatives over the analysis period (Hall et al., 2001). The purpose of the LCCA is to identify a rehabilitation strategy alternative with the lowest life cycle cost for the public. Here the cost is defined as the public cost, including the costs incurred by a highway agency for maintaining the pavement to a desired service level and the costs incurred by the road users during their use of the pavement.

A typical LCCA procedure consists of selecting an analysis period, selecting a discount rate, selecting a measure of economic worth, and determining monetary agency costs and user costs. A spreadsheet application developed by FDOT may be used for the analysis if user costs are not considered (FDOT, 2013), otherwise the FHWA RealCost software may be used (FHWA, 2017).

6.5.1 Selecting Analysis Period

Analysis period is a period over which the rehabilitation strategy alternatives for bridge approach/departure asphalt pavements are compared. The period for which a rehabilitation strategy is designed for is typically called a performance period. The analysis period can be defined in different ways, such as the least common multiple of the performance periods of all the alternatives, the shortest of the performance periods among the alternatives, and the longest of the performance periods among the alternatives. As shown in Figure 6-4, the common way is to select an analysis period equal to the performance period of the longest-surviving rehabilitation strategy alternative (Hall et al., 2001). For other alternatives with shorter performance periods, they will be applied for multiple times to fill out the selected analysis, as illustrated in Figure 6-4.

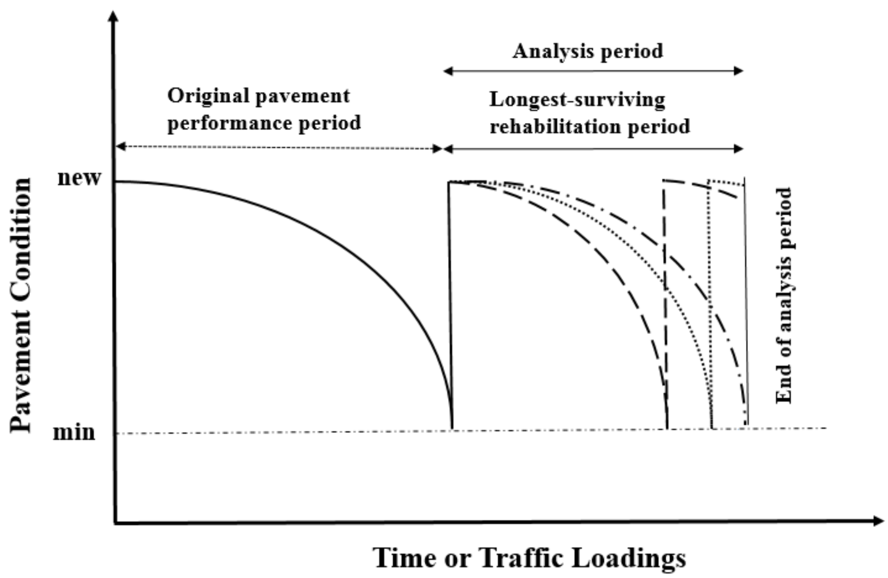


Figure 6-4 Selection of analysis period for alternatives with unequal performance periods

6.5.2 Selecting Discount Rate

The discount rate (k) is the rate of change over time in the true value of money, taking into account fluctuations in both the rate of inflation and investment interest rate. The discount rate used by state DOTs in life-cycle cost analysis varies from 0% to 10%, with 3% - 5% being the most typical range (Hall et al., 2001).

6.5.3 Selecting a Measure of Economic Worth

The economic worth of an investment can be measured in different ways, such as present worth method, annual worth method, future worth method. Rehabilitation alternatives considered in a life-cycle cost analysis need to be compared with the same measure of economic worth. The most commonly used measure of economic worth is present worth (Hall et al., 2001). Present worth method would express all costs and benefits over the analysis period in terms of their equivalent values in the initial year of the analysis period. To be specific, all costs incurred in the initial year are expressed as their actual present value. All future costs (e.g., follow-up rehabilitation construction costs) and future benefits (e.g., residual value at the end of the analysis period) need to be discounted to their equivalent present values. The general formula for discounting future cost or benefit ($\$F$) to present value ($\$P$) is shown in the following

$$\$P = \$F \times \frac{1}{(1+k)^n} \tag{6-5}$$

where k is the discount rate, n is the year in which future cost or benefit occurs.

6.5.4 Determining Monetary Agency Costs

Monetary agency costs are all those costs associated with rehabilitation alternatives that are incurred by the agency (e.g., FDOT) during the analysis period. Monetary agency costs include initial rehabilitation construction costs, possible follow-up rehabilitation construction, traffic control costs during construction work, and residual value of the pavement structure at the end of the analysis period.

To reasonably estimate construction costs and traffic control costs for different rehabilitation alternatives, a questionnaire survey over FDOT districts was conducted to collect average cost information about mobilization, TTC, milling, and overlay. The survey questions are designed as follows.

1. *What are the average contract lump sum prices for the item of mobilization (i.e., preparatory work and operations in mobilizing for beginning work) in bridge approach pavement milling/resurfacing and reconstruction project, respectively? (If data for bridge approach pavements are not available, please provide those for regular highway pavements.)*
2. *What is the average contract lump sum for TTC in bridge approach pavement rehabilitation areas? What are the average number of TTC days for bridge approach pavement milling/resurfacing and reconstruction project, respectively? (If data for bridge approach pavement areas are not available, please provide those for regular highway pavement area.)*
3. *What is the average cost of milling existing asphalt pavement at a certain depth (e.g., 1 in, 1 ½ in, 2 in, 2 ¾ in, 3 in, 4 in, 5 in, 6 in, and 7 in, etc.) per square yard (SY) in your district (for example, $2.77 per SY at 1 in depth)?*
4. *What is the average cost of overlay for a certain asphalt mixture type (e.g., SP-9.5, SP-12.5, SP-19, FC-5, FC-9.5, and FC-12.5, etc.) per ton (T) in your district?*

5. *Could you provide some previous cost-estimation contracts/reports (including overlay or reconstruction design, treatment area, cost-estimation lists, etc.) about milling & resurfacing or reconstruction of bridge approach pavement in your district (If files for bridge approach pavements are not available, please provide those for regular highway pavements.)?*

The detailed responses from all the participants of the survey are shown in Appendix G. Based on the responses, mobilization costs can be estimated as 8% to 20% of the total project cost. TTC costs can be estimated as 8% to 25% of the total project cost. TTC costs would vary depending on construction duration. Because the least interruption of traffic flow during repair of bridge approach pavement distresses is required, temporary traffic control plans can be conducted to facilitate road users through a work zone. The typical design of TTC for a short-section work zone is shown in Figure 6-5 (FHWA, 2009).

As shown in Figure 6-5, a work zone is typically marked by signs, channelizing devices, barriers, pavement markings. Based on the questionnaire survey results, the average cost for each construction pay item associated with bridge approach/departure asphalt pavement rehabilitation is summarized in Table 6-2. Asphalt concrete cost for overlay/reconstruction can be estimated as 110 lb per square yard per inch. More detailed information about each pay item can be found in the Basis of Estimates Manual (FDOT, 2010).

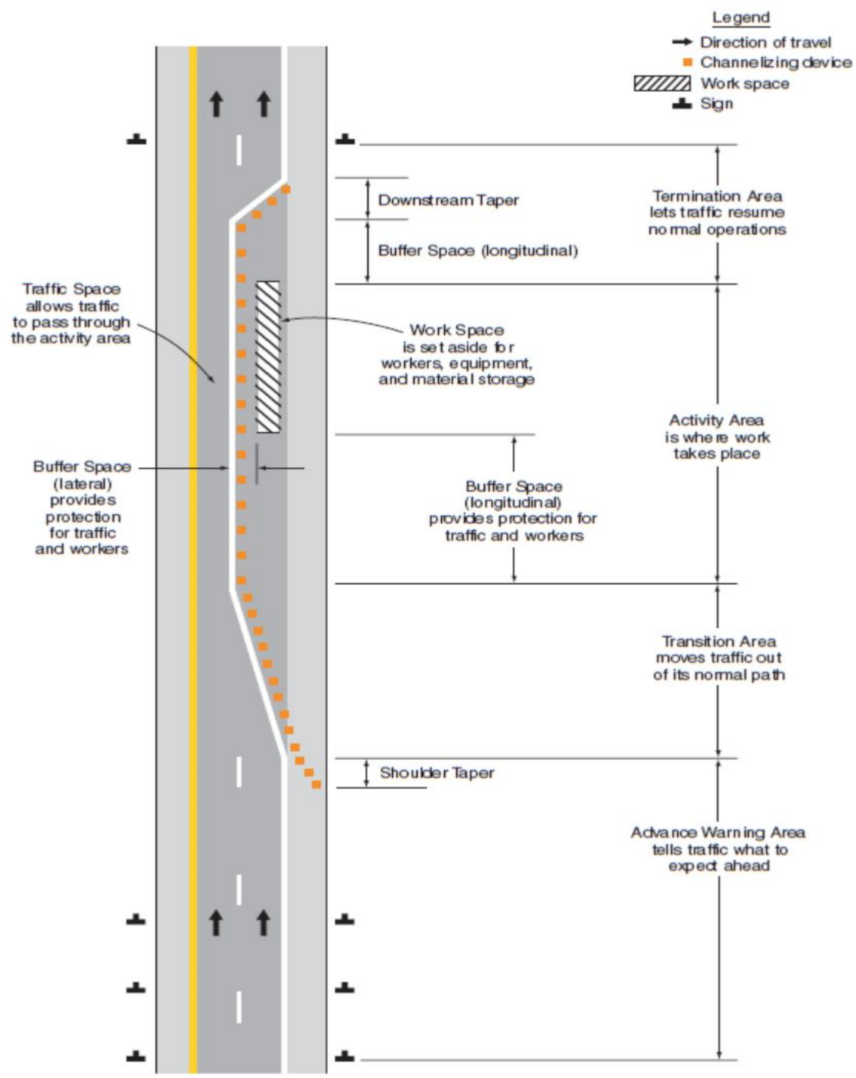


Figure 6-5 A typical design of TTC for a short section work zone (FHWA, 2009)

Table 6-2 List of item average unit cost associated with bridge pavement rehabilitation

Item	Description	Unit	Cost ($)
0101-1	Mobilization	Lump Sum	-
0102-1	Temporary traffic control	Day	500
0102-60	Work zone sign	Each Day	0.29
0102-71-13	Temporary barrier wall (Concrete)	Linear Foot	30.93
0102-74-1	Temporary channelizing device	Each Day	0.14
0102-76	Advance warning arrow panel	Each Day	5.55
0102-78	Temporary retroreflective pavement marker	Each	3.27
0102-150-1	Portable regulatory sign	Each Day	4.92
0285-710	Optional base, base group 10	yd^2	15.43
0285-711	Optional base, base group 11	yd^2	19.21
0285-712	Optional base, base group 12	yd^2	24.50

Table 6-2 List of item average unit cost associated with bridge pavement rehabilitation (continued)

Item	Description	Unit	Cost ($)
0285-713	Optional base, base group 13	yd^2	36.71
0285-714	Optional base, base group 14	yd^2	42.50
0285-715	Optional base, base group 15	yd^2	55.13
0287-1	Asphalt treated permeable base	yd^3	441.58
0327-70-16	Milling existing asphalt pavement, 1/2 in average depth	yd^2	1.68
0327-70-19	Milling existing asphalt pavement, 3/4 in average depth	yd^2	2.31
0327-70-1	Milling existing asphalt pavement, 1 in average depth	yd^2	2.56
0327-70-12	Milling existing asphalt pavement, 1-1/4 in average depth	yd^2	2.66
0327-70-6	Milling existing asphalt pavement, 1-1/2 in average depth	yd^2	2.76
0327-70-13	Milling existing asphalt pavement, 1-3/4 in average depth	yd^2	2.80
0327-70-5	Milling existing asphalt pavement, 2 in average depth	yd^2	2.93
0327-70-11	Milling existing asphalt pavement, 2-1/4 in average depth	yd^2	3.07
0327-70-8	Milling existing asphalt pavement, 2-1/2 in average depth	yd^2	3.43
0327-70-15	Milling existing asphalt pavement, 2-3/4 in average depth	yd^2	3.75
0327-70-4	Milling existing asphalt pavement, 3 in average depth	yd^2	3.92
0327-70-17	Milling existing asphalt pavement, 3-1/4 in average depth	yd^2	4.03
0327-70-2	Milling existing asphalt pavement, 3-1/2 in average depth	yd^2	4.26
0327-70-20	Milling existing asphalt pavement, 3-3/4 in average depth	yd^2	4.67
0327-70-7	Milling existing asphalt pavement, 4 in average depth	yd^2	4.93
0327-70-22	Milling existing asphalt pavement, 4-1/4 in average depth	yd^2	5.30
0327-70-3	Milling existing asphalt pavement, 4-1/2 in average depth	yd^2	5.71
0327-70-26	Milling existing asphalt pavement, 4-3/4 in average depth	yd^2	5.81
0327-70-10	Milling existing asphalt pavement, 5 in average depth	yd^2	6.64
334-1-51	Superpave asphaltic concrete, traffic level A, PG 76-22	T	300.00
334-1-52	Superpave asphaltic concrete, traffic level B, PG 76-22	T	325.00
334-1-53	Superpave asphaltic concrete, traffic level C, PG 76-22	T	350.00
334-1-54	Superpave asphaltic concrete, traffic level D, PG 76-22	T	375.00
334-1-55	Superpave asphaltic concrete, traffic level E, PG 76-22	T	400.00
337-7-25	Asphaltic concrete friction course, FC-5, PG 76-22	T	400.00
0327-70-9	Milling existing asphalt pavement, 5-1/4 in average depth	yd^2	6.75
0327-70-19	Milling existing asphalt pavement, 5-1/2 in average depth	yd^2	7.20
0327-70-27	Milling existing asphalt pavement, 5-3/4 in average depth	yd^2	7.45
0327-70-23	Milling existing asphalt pavement, 6 in average depth	yd^2	8.00
0327-70-14	Milling existing asphalt pavement, 6-1/2 in average depth	yd^2	8.75
0327-70-21	Milling existing asphalt pavement, 7 in average depth	yd^2	9.20
0327-70-31	Milling existing asphalt pavement, 7-1/2 in average depth	yd^2	10.25
0327-70-33	Milling existing asphalt pavement, 7-3/4 in average depth	yd^2	10.40

The residual value of a rehabilitation alternative is the value that can be attributed to the alternative at the end of the analysis period. The residual value can be determined as the portion of the cost of the last rehabilitation equal to the portion of the remaining life of the last rehabilitation (Walls and Smith, 1998).

6.5.5 Determining User Costs

User costs are the costs incurred by road users under a rehabilitation scenario. User costs include vehicle operating costs (e.g., consumption of fuel and oil, and wear on tires and other vehicle parts), delay costs (e.g., reduced speed in work zone), and accident costs (e.g., high accident rate in work zone). Due to the absence of pavement performance models and fuel consumption models, vehicle operating costs cannot be accurately estimated. The FHWA RealCost software may be used for user delay cost analysis, but it requires inputs of detailed traffic data, which may not be readily available for a project site (FHWA, 2017). As a general rule, delay costs and accident costs would increase with the total construction duration and maintenance frequency over the analysis period. The production rates used to estimate rehabilitation construction duration are listed in Table 6-3 (Ohio DOT, 1999).

Table 6-3 Paving and rehabilitation work production rates

Item Description	Production Rate
Wearing course removal	11,250 yd^2/day
Pavement removal	2,250 yd^2/day
Base removal	1,000 yd^3/day
Subgrade compaction	1 day/lane
Cold milling of asphalt	8,750 yd^2/day
Asphalt concrete friction course	1,124 yd^3/day
Asphalt concrete structural course	625 yd^3/day

6.5.6 Summary

After a few rehabilitation strategy alternatives are formed for a bridge approach/departure asphalt pavement, a life-cycle cost analysis (LCCA) may be performed to help identify the alternative with the lowest public cost, including agency costs and user costs, over an analysis period. The LCCA procedure consists of selecting an analysis period, selecting a discount rate, selecting a measure of economic worth, and determining monetary agency costs and user costs. A spreadsheet application developed by FDOT may be used for the LCCA if user costs are not considered, otherwise the FHWA RealCost software may be used if sufficient traffic data are available. As a general rule, the user costs, in terms of delay and accident costs, would increase with the total construction duration and maintenance frequency over the analysis period.

6.6 Selection of Rehabilitation Strategy

6.6.1 Selection of Rehabilitation Strategy

The LCCA results may be used as a main criterion to select the rehabilitation strategy. A strategy with the lowest life cycle cost among all strategy alternatives should be selected.

A complete LCCA to quantify all possible agency and user costs, however, is sometimes difficult to perform due to lack of information. Some agency or user costs may not be accurately measured in monetary terms, such as worker risk during construction, user accident and delay during construction, and increased user vehicle wear and tear and fuel consumption due to pavement distresses. In this case, those costs may be excluded from the LCCA, treated as nonmonetary factors and qualitatively assessed. As a general trend, user costs should increase with the increase of rehabilitation frequency and construction duration. Some other nonmonetary factors may also influence the strategy selection, such as environmental impact, agency or contractor's experience with the rehabilitation techniques, limit on construction space, and availability of needed equipment. The final selection, therefore, should be based on the LCCA, budget limitations, and consideration of nonmonetary factors.

A comparison table may be used to list the life cycle cost and nonmonetary factors of each rehabilitation strategy alternative for overall consideration and comparison. One example of such a table is shown in Table 6-4. It is recommended that at least two rehabilitation strategy alternatives be considered.

Table 6-4 Comparison table example for selection of rehabilitation strategy

Rehabilitation Strategy	Life-Cycle Cost	Rehabilitation Frequency	Construction Duration	Equipment Accessibility	Material Availability
1					
2					
3					
4					

6.6.2 Identification of Obstacles for Bridge Approach/Departure Asphalt Pavement Repairs

To make the rehabilitation alternatives more feasible and practical, a questionnaire survey over Florida pavement M&R contractors was conducted to identify the obstacles in the construction process of bridge approach/departure asphalt pavement repairs. The survey questions are listed as follows.

1. *Do you have any experience with M&R of asphalt pavements on bridge approaches/departures? (If the answer is No, you may skip the rest of the questions.)*
2. *Based on your experience, are there any additional rehabilitation obstacles (e.g., deployment of equipment, temporary traffic control, efficiency of M&R work) for M&R of bridge approach/departure asphalt pavements compared to M&R of pavements on regular roadways? If yes, please give a brief description of them.*
3. *Have you had a way, or do you have any suggestion, to overcome the obstacles mentioned above? If yes, please give a brief description.*

Based on the responses, the typical obstacle identified in the rehabilitation construction of bridge approach/departure asphalt pavements is limited work space because at least one lane needs to be open to the traffic. The practical way to make it easier for the contractor would be narrowing the open lane or adding temporary asphalt pavement along the median.

6.6.3 An Example of Selection of Rehabilitation Strategy for Bridge Approach/Departure Asphalt Pavements

This section provides an example to illustrate the step-by-step procedure for bridge approach/departure asphalt pavement rehabilitation strategy selection proposed in this study. The example is based on the pavement condition survey report (FIN 428804-1-52-01) for bridge approaches (Bridge Number is 260079) investigated in 2013 (Moseley, 2013). Some of the data for this example were drawn from this resource, and the other data were reasonably assumed.

Step 1. Pavement Condition Survey and Evaluation

The bridge approach pavement section is firstly identified as a 200 ft transition area from the end of a bridge approach slab. The mean values of pavement performance indicators (e.g., crack rating, rut depth, IRI) are calculated over the bridge approach pavement section and the control section, respectively. The results are listed in Table 6-5.

Table 6-5 Pavement condition survey results

Performance Indicator	Bridge Approach Pavement	Control Section
Crack Rating	6.9	9.5
Rut Depth (in)	0.58	0.16
IRI (in/mi)	157.7	74.9

The condition of the bridge approach pavement is evaluated with its corresponding control section from the following three aspects: smoothness, structural distresses, and drainage condition. The evaluation results are summarized in Table 6-6, from which it can be seen that the overall evaluation for the bridge approach pavement condition is “poor”.

Table 6-6 Performance evaluation result for bridge approach pavement

Performance Condition Indicator	Evaluation Result
Smoothness	Poor
Structural Distresses	Poor
Drainage Condition	No drainage related symptoms in the survey report, such as excessively high moisture content, clogging of edge drains.

Step 2. Detailed Data Collection

The detailed information of the poor bridge approach pavement is extracted from pavement condition survey reports and RCI database, illustrated as follows. This bridge approach pavement section is in the Alachua County of District 2 in Florida. The speed limit is 70 mph. This section is a six-lane divided roadway with paved shoulders. The width of lanes is 12 ft. The base for the travel lane and shoulders is limerock (LR). In 2013, the AADT and AADTT for this section were 70,000 and 12,950 vehicles per day, respectively. The BMP and EMP for the bridge are 9.701 and 9.739, respectively. The resilient modulus of roadbed soil is 18,000 psi. The layer thicknesses for bridge approach pavement and control section are 6-3/4 in and 15-1/2 in, respectively. The specific pavement structure extracted from pavement coring and evaluation report is shown in Table 6-7. The critical cracking depth is identified as 2-1/2 in. The layer causing the rutting was determined as the first structural course layer which is associated with a lack of stability (Scullion, 2001). Based on GPR test results, subsurface condition was fine.

Table 6-7 Existing pavement structure

Material	Layer Thickness (in)
Friction Course, FC-5	3/4
Structural Course, SP-12.5	2
Structural Course, SP-19.0	4
Base Course, LR	10
Stabilized Subgrade, LBR-40	12

Step 3. Selection of Rehabilitation Technique

Based on the existing pavement structure shown in Table 6-7, structural overlay and reconstruction can be chosen to address the pavement distress issues (e.g., rutting and cracking) for structural improvement.

Step 4. Formation of Rehabilitation Strategies

Five rehabilitation alternatives are developed based on traffic analysis, existing pavement structure and condition. The design periods for milling and inlay are set as 8, 15, 20, and 30 years, respectively. The design period for reconstruction is 30 years. The $ESAL_D$ over the 8-year design period is 8 million (Traffic Level C) which can be obtained from FDOT District Planning Office. The $ESAL_D$ over the 15-year design period is 20 million (Traffic Level D), and the $ESAL_D$ values over the 20-year and 30-year design periods are 33 million (Traffic Level E) and 100 million (Traffic Level E), respectively. The design reliability of rehabilitation is set as 99%. The required structural numbers (SN_R) for four rehabilitation alternatives, as shown in Table 6-8, can be obtained using Appendix A of the FDOT FPDM (FDOT, 2016b).

Table 6-8 Required structural number for rehabilitation strategy alternatives

Rehabilitation Strategy	$ESAL_D$	Traffic Level	SN_R
8-Year Milling and Inlay	8,000,000	C	4.16
15-Year Milling and Inlay	20,000,000	D	4.78
20-Year Milling and Inlay	33,000,000	E	5.13
30-Year Milling and Inlay	100,000,000	E	5.97
30-Year Reconstruction	100,000,000	E	5.97

The existing structural number (SN_E) for the bridge approach pavement without milling and inlay is calculated using the procedure shown in Table 6-9. As can be seen, the existing structural number (3.66) is lower than the required structural numbers for different design periods.

Table 6-9 Existing structural number of bridge approach pavement without milling

Layer Type	Thickness (D_i)	Reduced Layer Coefficient (a_i)	SN_E
Structural Course, SP	6	0.15	0.90
Base Course, LR	10	0.18	1.80
Subbase Course, LR	0	0.16	0.00
Stabilized Subgrade, LBR-40	12	0.08	0.96
Entire Structure of the Existing Pavement			3.66

If the entire asphalt layer of the existing pavement is milled and inlayed with new structural and friction courses, the new structural number SN_N is calculated as

$$SN_N = 0.44D_1 + \sum_{i=2}^{4} a_i D_i = 0.44 \times 6 + 10 \times 0.18 + 0 \times 0.16 + 12 \times 0.08 = 5.40$$

(1) 8-Year Milling and Inlay

Since the required structural number for the "8-Year Milling and Inlay" rehabilitation strategy is less than the structural number when the entire asphalt layer is milled and inlayed (i.e., $SN_R = 4.16 \leq SN_N = 5.40$), the minimum milling depth of the structural course layer (d_1) can be determined from the following inequality:

$$SN_D = 0.44d_1 + a_1(D_1 - d_1) + \sum_{i=2}^{4} a_i D_i > SN_R$$

$$0.44d_1 + 0.15(6 - d_1) + 10 \times 0.18 + 0 \times 0.16 + 12 \times 0.08 > 4.16$$

$$d_1 > 1.72$$

So, d_1 is set as 2.0 in. The final milling depth is 2-3/4 in, with the 3/4 in friction course thickness included, which is enough to address both cracking (i.e., the critical cracking depth is 2-1/2 in) and rutting (i.e., the first structural layer). The final structural number for the bridge approach pavement after rehabilitation is 4.24.

(2) 15-Year Milling and Inlay

Since the required structural number for the "15-Year Milling and Inlay" rehabilitation strategy is also less than the structural number when the entire asphalt layer is milled and inlayed (i.e., $SN_R = 4.78 \leq SN_N = 5.40$), the minimum milling depth of the structural course (d_1) can be determined from the following inequality:

$$SN_D = 0.44d_1 + a_1(D_1 - d_1) + \sum_{i=2}^{4} a_i D_i > SN_R$$

$$0.44d_1 + 0.15(6 - d_1) + 10 \times 0.18 + 0 \times 0.16 + 12 \times 0.08 > 4.78$$

$$d_1 > 3.86$$

So, d_1 is set as 4.0 in. The final milling depth is 4-3/4 in, with the 3/4 in friction course thickness included. The final structural number for the bridge approach pavement after rehabilitation is 4.82.

(3) 20-Year Milling and Inlay

In rehabilitation for a 20-year design period, the existing 10 in granular base (LR) may be retained while the entire asphalt layer is removed and replaced new asphalt mixtures. In this case, the required structural number is less than the trial design structural number (i.e., $SN_R = 5.13 < SN_D = 5.40$). So, d_1 is set as 6.0 in. The final milling depth is 6-3/4 in, with the 3/4 in friction course thickness included. The final structural number for the bridge approach pavement after rehabilitation is 5.40.

(4) 30-Year Milling and Inlay

Since the required structural number for the "30-Year Milling and Inlay" rehabilitation strategy is greater than the structural number when the entire asphalt layer is milled and inlayed (i.e., $SN_R = 5.97 > SN_N = 5.40$), the milling depth will go into the base layer. The minimum milling depth of the base layer (d_2) can be determined from the following inequality:

$$SN_D = (0.44 - a_2)d_2 + SN_N > SN_R$$
$$(0.44 - 0.15)d_2 + 5.40 > 5.97$$
$$d_2 > 2.19$$

So, d_2 is set as 2.5 in. The final milling depth is 9-1/4 in, with the thickness of existing asphalt pavement included. The final structural number for the bridge approach pavement after rehabilitation is 6.05.

(5) 30-Year Reconstruction

In reconstruction for a 30-year design period, the existing 10 in granular base (LR) may be replaced with an asphalt treated base. If the base group 9 (6 in Type B-12.5) is selected to replace the current 10 in LR base, 4 in more asphalt structural course may be paved to increase the structural number. The possible reconstruction strategies over the 30-year design period are summarized in Table 6-10.

Table 6-10 Design structural number for different reconstruction strategies

Base Group	Structural Course Thickness (in)	SN_D
9 (6 in Type B-12.5)	10	7.16
10 (6-1/2 in Type B-12.5)	9-1/2	7.09
11 (7 in Type B-12.5)	9	7.02
12 (7-1/2 in Type B-12.5)	8-1/2	6.95
13 (8 in Type B-12.5)	8	6.88
14 (8-1/2 in Type B-12.5)	7-1/2	6.81
15 (9 in Type B-12.5)	7	6.74

Based on Table 6-10, the design structural number for all possible reconstruction strategies is greater than the required structural number. Because the unit cost of asphalt concrete (T) is greater than that of asphalt treated base, base group 15 (9 in Type B-12.5) is selected as the new base layer for bridge approach pavement reconstruction. The final structural number for the bridge approach pavement after reconstruction is 6.74.

After the milling depth (for rehabilitation) and base group (for reconstruction) are determined, asphalt materials selection and thickness design can be easily conducted following the FDOT FPDM (FDOT, 2016b). The specific selected asphalt material and thickness for five rehabilitation alternatives are summarized in Table 6-11. The asphalt binder type for the structural course and the friction course is selected as PG 76-22.

Table 6-11 Resurfacing/reconstruction design for rehabilitation alternatives

Material Type	8-Year Inlay (in)	15-Year Inlay (in)	20-Year Inlay (in)	30-Year Inlay (in)	30-Year Reconstruction (in)
FC-5	3/4	3/4	3/4	3/4	3/4
SP-12.5	2	2	2	2-1/2	2
SP-12.5	-	2	-	3	2
SP-19.0	-	-	4	3	3
Type B-12.5	-	-	-	-	9

Step 5. Life-Cycle Cost Analysis (LCCA)

The procedure of the LCCA consists of selecting an analysis period, a discount rate, and a measure of economic worth, and determining monetary agency costs and user costs. The selected analysis period for the above five rehabilitation strategy alternatives is 30 years (i.e., the longest of the performance periods among the alternatives). The discount rate is assumed to be 4%. The present worth expressing all costs and benefits over the analysis period in terms of their equivalent value in the initial year of the analysis period is selected as the measure of economic worth. Monetary agency costs include initial rehabilitation construction costs, possible follow-up rehabilitation construction, traffic control costs during construction work, and residual value of the pavement structure at the end of the analysis period. The typical construction area for the bridge approach pavement is set as a rectangular area (200 ft length by 12 ft width). Mobilization costs can be estimated as 15% of the total project cost. TTC costs can be estimated as 15% of the total project cost. Then, the construction cost (e.g., milling cost, resurfacing cost, reconstruction cost, etc.) would account for 70% of the total project cost. The residual cost can be determined as the portion of the cost of the last rehabilitation equal to the proportion of the remaining life of the last rehabilitation (Walls and Smith, 1998).

Determine Monetary Agency Costs

(1) 8-Year Milling and Inlay

The milling depth for the 8-year milling and inlay strategy is 2-3/4 in. Based on Table 6-2, the average unit cost for milling existing asphalt pavement at a depth of 2-3/4 in is \$3.75 per square yard. Then, the total milling cost is

$$(200 \times 12)/9 \times 3.75 = 1{,}000\ (\$)$$

The resurfacing design is 3/4 in friction course (FC-5) and 2 in structural course (SP-12.5, traffic level C). Based on Table 6-2, the average unit cost of friction course is \$400 per ton. The average unit cost of structural course (traffic level C, PG 76-22) is \$350 per ton. Asphalt concrete cost can be estimated as 110 lb per square yard per inch. Then, the total resurfacing cost is

$$\frac{200 \times 12}{9} \times \frac{110}{2{,}000} \times \left(\frac{3}{4} \times 400 + 2 \times 350\right) = 14{,}666.7(\$)$$

Then, the total initial rehabilitation cost is

$$\frac{14{,}666.7 + 1{,}000}{70\%} \approx 22{,}381(\$)$$

Finally, the total rehabilitation cost over the analysis period is

$$\frac{22{,}381}{(1+4\%)^{0}} + \frac{22{,}381}{(1+4\%)^{8}} + \frac{22{,}381}{(1+4\%)^{16}} + \frac{22{,}381}{(1+4\%)^{24}} \times \left(1 - \frac{2}{8}\right) \approx 57{,}232(\$)$$

(2) 15-Year Milling and Inlay

The milling depth for the 15-year milling and inlay strategy is 4-3/4 in. Based on Table 6-2, the average unit cost for milling the existing asphalt pavement at a depth of 4-3/4 in is $5.81 per square yard. Then, the total milling cost is

$$(200 \times 12)/9 \times 5.81 = 1{,}549.3\ (\$)$$

The resurfacing design is 3/4 in friction course (FC-5) and 4 in structural course (SP-12.5, traffic level D). Based on Table 6-2, the average unit cost of friction course is $400 per ton. The average unit cost of structural course (traffic level D, PG 76-22) is $375 per ton. Asphalt concrete cost can be estimated as 110 lb per square yard per inch. Then, the total resurfacing cost is

$$\frac{200 \times 12}{9} \times \frac{110}{2{,}000} \times \left(\frac{3}{4} \times 400 + 4 \times 375\right) = 26{,}400(\$)$$

Then, the total initial rehabilitation cost is

$$\frac{26{,}400 + 1{,}549.3}{70\%} \approx 39{,}928(\$)$$

Finally, the total rehabilitation cost over the analysis period is

$$\frac{39{,}928}{(1+4\%)^{0}} + \frac{39{,}928}{(1+4\%)^{15}} \approx 62{,}099(\$)$$

(3) 20-Year Milling and Inlay

The total removal work for the 20-year milling and inlay design is 6-3/4 in asphalt pavement. Based on Table 6-2, the average unit cost for milling existing asphalt pavement at a depth of 6-3/4 in is $9.00 per square yard. Then, the total cost for removal work is

$$(200 \times 12)/9 \times 9.00 = 2{,}400\ (\$)$$

The rehabilitation design is a 3/4 in friction course (FC-5) and a 6 in structural course (traffic level E). Based on Table 6-2, the average unit cost of friction course is $400 per ton. The average unit cost of structural course (traffic level E, PG 76-22) is $400 per ton. Asphalt concrete cost can be estimated as 110 lb per square yard per inch. Then, the total resurfacing cost is

$$\frac{200 \times 12}{9} \times \frac{110}{2{,}000} \times \left(\frac{3}{4} \times 400 + 6 \times 400\right) = 39{,}600(\$)$$

Then, the total initial rehabilitation cost is

$$\frac{2{,}400 + 39{,}600}{70\%} = 60{,}000(\$)$$

Assuming a second rehabilitation will be conducted at the end of the 20th year, the total rehabilitation cost over the 30-year analysis period is

$$\frac{60{,}000}{(1 + 4\%)^0} + \frac{60{,}000}{(1 + 4\%)^{20}} \times \left(1 - \frac{10}{20}\right) \approx 73{,}692(\$)$$

(4) 30-Year Milling and Inlay

The total milling depth for 30-year milling and inlay strategy is 9-1/4 in (i.e., 6-3/4 in asphalt pavement and 2-1/2 in base layer). Based on Table 6-2, the average unit cost for milling existing asphalt pavement at a depth of 6-3/4 in is $9.00 per square yard. The average unit cost for milling base layer at a depth of 2-1/2 in is assumed to be $10.00 per square yard. Then, the total milling cost is

$$(200 \times 12)/9 \times (9.00 + 10.00) = 5{,}066.7\ (\$)$$

The resurfacing design is a 3/4 in friction course (FC-5) and an 8-1/2 in structural course (traffic level E). Based on Table 6-2, the average unit cost of friction course is $400 per ton. The average unit cost of structural course (traffic level E, PG 76-22) is $400 per ton. Asphalt concrete cost can be estimated as 110 lb per square yard per inch.

Then, the total resurfacing cost is

$$\frac{200 \times 12}{9} \times \frac{110}{2{,}000} \times \left(\frac{3}{4} \times 400 + 8\frac{1}{2} \times 400\right) \approx 54{,}267(\$)$$

Finally, the total rehabilitation cost over the analysis period is

$$\frac{54{,}267 + 5{,}066.7}{70\%} \approx 84{,}762(\$)$$

(5) 30-Year Reconstruction

The total removal work for the 30-year reconstruction design is 6-3/4 in asphalt pavement and 10 in limerock base layer. Based on Table 6-2, the average unit cost for milling existing asphalt pavement at a depth of 6-3/4 in is $9.00 per square yard. The average unit cost for removing the base layer at a depth of 10 in is assumed to be $50.00 per square yard. Then, the total cost for removal work is

$$(200 \times 12)/9 \times (9.00 + 50.00) = 15{,}733.3\ (\$)$$

The reconstruction design is a 3/4 in friction course (FC-5), a 7 in structural course (traffic level E), and a base group 15 (9 in Type B-12.5). Based on Table 6-2, the average unit cost of friction course is $400 per ton. The average unit cost of structural course (traffic level E, PG 76-22) is $400 per ton. The average unit cost for base group 15 is $55.13 per square yard. Asphalt concrete cost can be estimated as 110 lb per square yard per inch.

Then, the total resurfacing cost is

$$\frac{200 \times 12}{9} \times \left[\frac{110}{2{,}000} \times \left(\frac{3}{4} \times 400 + 7 \times 400\right) + 55.13\right] = 60{,}168(\$)$$

Finally, the total rehabilitation cost over the analysis period is

$$\frac{60{,}168 + 15{,}733.3}{70\%} \approx 108{,}430(\$)$$

Determine User Costs

Due to the absence of pavement performance models and fuel consumption models, vehicle operating costs cannot be accurately estimated. Delay costs and accident costs would increase with the total construction duration and rehabilitation frequency over the analysis period. The rehabilitation frequency for different alternatives is shown in Figure 6-6.

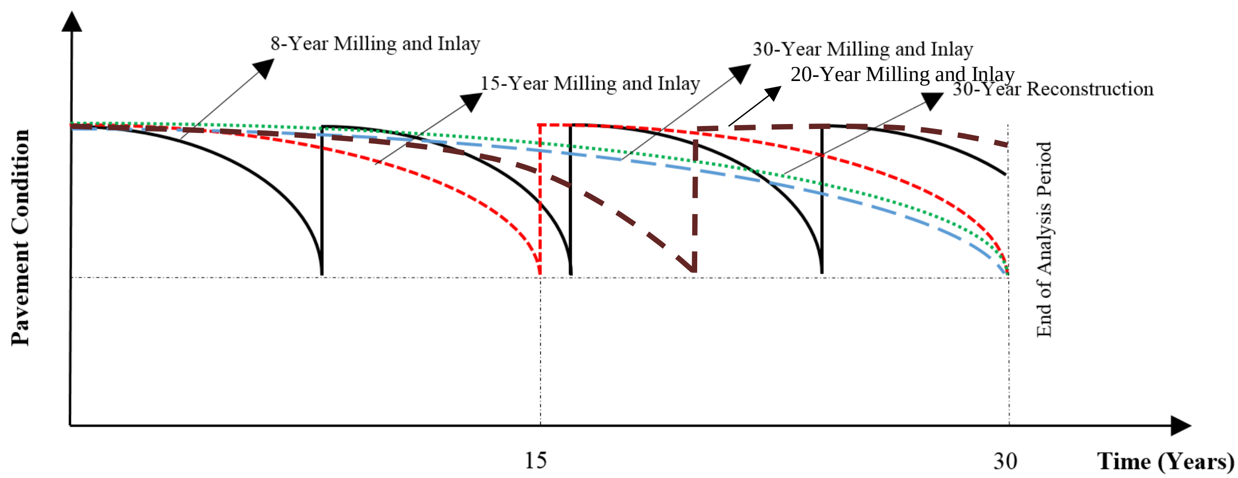


Figure 6-6 Rehabilitation strategy alternatives over 30-year analysis period

The construction duration for each rehabilitation strategy can be estimated using the production rates listed in Table 6-3. The estimation results for different alternatives are shown in Table 6-12.

Table 6-12 Construction duration (days) for rehabilitation strategy alternatives

Item	8-Year Milling & Inlay	15-Year Milling & Inlay	20-Year Milling & Inlay	30-Year Milling & Inlay	30-Year Reconstruction
Mobilization and MOT	1	1	1	1	1
Pavement removal	1	1	1	1	1
Base removal	0	0	0	1	1
Base work	0	0	0	0	1
Resurfacing or reconstruction	1	1	1	1	1
Equipment departure	1	1	1	1	1
Overall	4	4	4	5	6

Step 6. Selection of Rehabilitation Strategy

The comparison table for selection of rehabilitation strategy is shown in Table 6-13.

Table 6-13 Comparison analysis for selection of rehabilitation strategy

Rehabilitation Strategy	Life-Cycle Agency Cost ($)	Rehabilitation Frequency	Total Construction Duration (day)	SN Improvement
8-Year Milling and Inlay	57,232	4	16	0.58
15-Year Milling and Inlay	62,099	2	8	1.16
20-Year Milling and Inlay	73,692	2	8	1.74
30-Year Milling and Inlay	84,762	1	5	2.39
30-Year Reconstruction	108,430	1	6	3.08

The selected rehabilitation strategy for bridge approach pavement should minimize the total life-cycle cost. In this case study, the user costs are not quantitatively determined. However, considering the high traffic volume (an AADT of 70,000), it is expected that the user delay cost due to rehabilitation work would be high. Since the differences between the life-cycle agency costs of the five strategies are small, a rehabilitation strategy with a low rehabilitation frequency should be selected to reduce traffic interruptions. Based on these considerations, the 30-year milling and inlay option would be the best rehabilitation strategy for the bridge approach pavement.

In this example, in the “8-Year Milling and Inlay” and “15-Year Milling and Inlay” rehabilitation strategies, the milling depths (2.75 and 4.75 in) exceed the critical cracking depth (2.5 in), but are less than the total asphalt layer thickness (6.75 in). These designs will leave the original structural course SP-19.0 in place as part of the rehabilitated asphalt concrete layer.

Although the remained SP-19.0 course is below the critical cracking depth, it is possible that cracks exist in this course. Without effective treatment for reflective cracking, cracks may quickly propagate into the asphalt overlay and lead to premature failure of the rehabilitated pavement. The actual life cycle costs of the 8-year and 15-year rehabilitation strategies, therefore, are likely to be higher than those shown in Table 6-13. This concern further supports the selection of the 30-year milling and inlay option as the best rehabilitation strategy.

The difference in agency costs between the 20-year and 30-year design periods is around $11,070 (for 20- and 30-year milling and inlay) or $34,738 (for 20-year milling and inlay and 30-year reconstruction) for a 200 ft by 12 ft bridge approach pavement section for a 30-year analysis period. If detailed traffic information was available to allow estimation of the user costs, the increased user costs due to the extra rehabilitation scheduled at the end of the 20th year for the 20-year rehabilitation strategy may be compared with this cost difference, and a decision may be made with more confidence. For the high AADT in this example, the increased user costs are likely much higher than $34,738 based on the user cost information available in the literature. For example, using a typical hourly value of vehicle delay time of $38.27/vehicle-hr for intercity personal travel (Mallela and Sadasivam, 2011), the user delay cost will amount to $\$38.27 \times 70{,}000/2 \times 10/60 = \$223{,}242$ per day if each vehicle in one travel direction is assumed to be delayed for only 10 minutes in a day. Therefore, the 30-year design period would be preferred to the 20-year design period.

6.7 Summary

The procedure proposed for rehabilitation strategy selection for bridge approach/departure asphalt pavements is summarized in Figure 6-7.

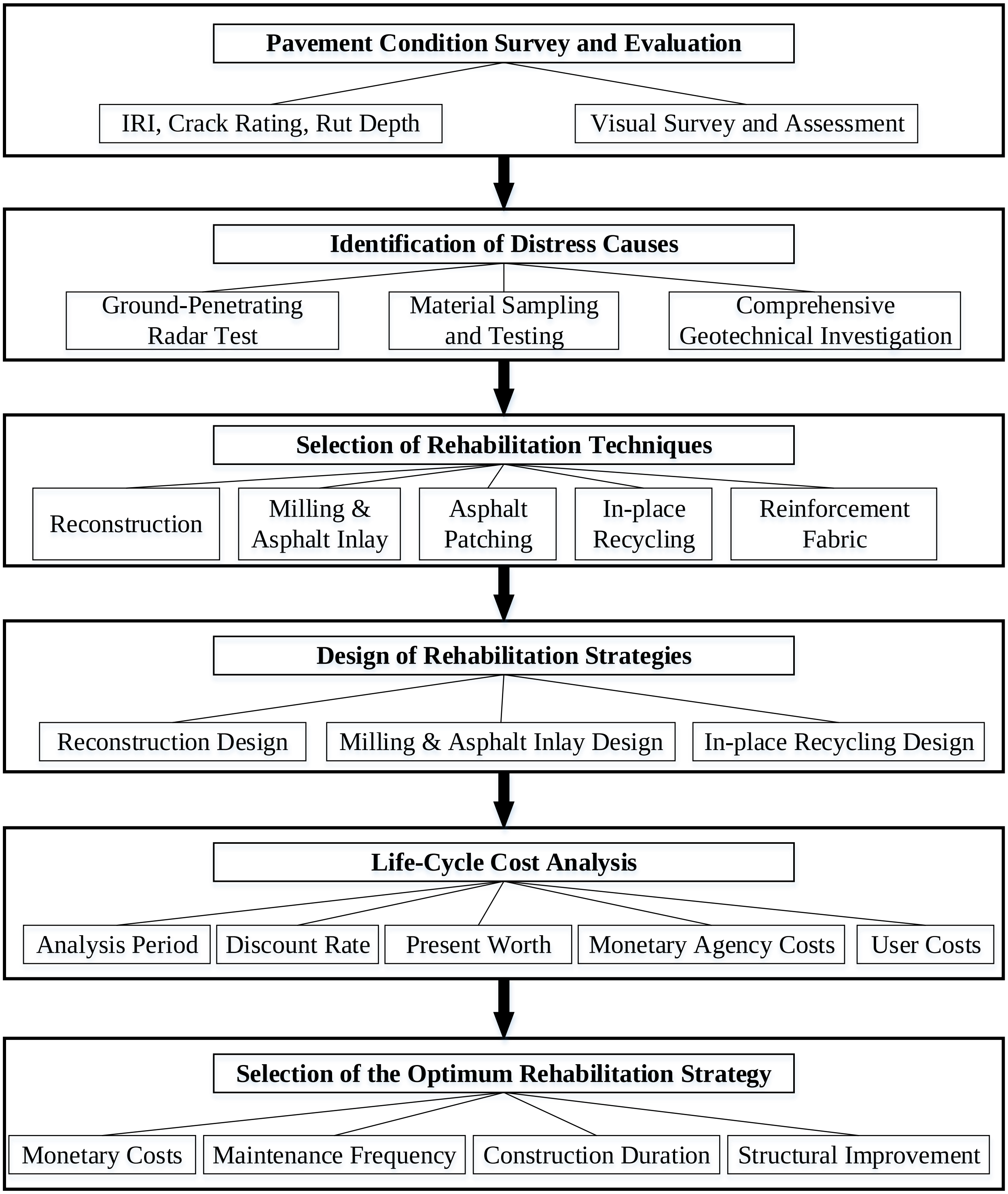


Figure 6-7 Rehabilitation strategy selection procedure for bridge approach/departure asphalt pavements

CHAPTER 7 POTENTIAL CHANGES TO FDOT PAVEMENT PRACTICES

The proposed procedure for rehabilitation strategy selection for bridge approach/departure asphalt pavements will require some changes to the current FDOT pavement practices for bridge approach/departure asphalt pavements. Those suggested changes are summarized in Table 7-1.

Table 7-1 Suggested changes to current FDOT pavement rehabilitation practices

Item	Current Practice	Suggested Changes
Pavement Condition Survey and Evaluation	No special consideration is given in pavement condition survey and evaluation to bridge approach/departure asphalt pavements.	Bridge approach/departure pavements should be considered as special sections in pavement condition survey and evaluation, and recorded as separate pavement sections in pavement condition database.
As-built Data	Material sampling and testing are typically not conducted on bridge approach/departure asphalt pavements during pavement construction or rehabilitation.	As part of quality control (QC) and quality assurance (QA) during pavement construction or rehabilitation, material samples (e.g., cores) should be taken from the bridge approach pavement and tested, in the same way as for control sections.
Special Pavement Test	The GPR test is performed on a pavement section upon special requests, and the GPR data are recorded at a spacing of 100 ft.	If a bridge approach pavement is deemed in need of rehabilitation and its structure information is not available, the GPR test may be performed to measure pavement layer thickness and moisture content, with the data resolution of around 6 ft of pavement per trace.
Rehabilitation Techniques	A short-term maintenance approach (e.g., patching and crack sealing) is commonly used to address bridge approach pavement distresses.	If the condition of a bridge approach pavement is rated as poor based on condition survey and evaluation, a long-term rehabilitation plan should be considered to reduce maintenance frequency and corresponding traffic interruptions.
Rehabilitation Strategies	Bridge approach/departure pavements are typically rehabilitated at the same time and in the same way as their control sections. Bridge approach/departure asphalt pavements are typically milled with a thickness of 2-3/4 in and resurfaced with a 2 in Type SP structural asphalt and a 3/4 in FC-5 friction course. The design period for flexible pavement reconstruction is 20 years.	If a bridge approach/departure asphalt pavement shows distresses worse than its control section, it should be considered for rehabilitation individually. The milling and inlay design for bridge approach/departure asphalt pavements needs to vary with existing pavement conditions, pavement structures, and truck traffic volumes. The specific milling and inlay depth can be determined following the modified structural deficiency approach, with measures to prevent reflective cracking such as placement of a geotextile fabric interlayer. In-place recycling with asphalt overlay may also be considered as one rehabilitation option, including full depth reclamation. A 30-year rehabilitation design period is recommended for bridge approach/departure asphalt pavements on Interstate highways with high traffic volumes. This is because the difference in agency costs would be small compared to the increased user cost due to increased rehabilitation frequency, as illustrated in the example in Chapter 6.

Table 7-1 Suggested changes to current FDOT pavement rehabilitation practices (continued)

Life-Cycle Cost Analysis for Rehabilitation Strategy Alternatives	Life-cycle cost analysis (LCCA) has not been considered in the bridge approach pavement rehabilitation practices.	LCCA may be conducted to identify the cost-effective rehabilitation strategy for bridge approach/departure asphalt pavements. The LCCA spreadsheet application developed by FDOT or the FHWA RealCost software may be used for this purpose.
Selection of the Best Rehabilitation Strategy	A short-term maintenance approach is commonly accepted. One-time agency costs are weighed more important than the other factors (e.g., maintenance frequency).	The selected rehabilitation strategy for bridge approach/departure asphalt pavements should minimize the total life-cycle cost, including both agency costs and user costs.

The suggested changes to current FDOT pavement practices will require involvement and commitment of relevant Department offices such as materials offices and pavement management sectors at the state and/or district level. Changes of work process will be mainly in the following aspects:

- During rehabilitation or construction of asphalt pavements incorporating a bridge approach pavement, material sampling and testing effort is increased to ensure the bridge approach pavement is tested during QC/QA.
- The current segmentation of pavement sections in pavement annual condition database needs to be refined to isolate the bridge approach pavement sections. Software used to collect and process pavement condition data needs to be updated for such change.
- The GPR test may need to be conducted on a large number of bridge approach pavements. There are about 1,155 bridges with asphalt approach pavements on Florida Interstate highways, and about 27% of them showed signs of cracking and 20% of them showed signs of rutting based on video log images and 2014-2015 pavement condition survey data. GPR data are currently available for only 75 out of the 1,155 bridges.
- Extra design and analysis effort is needed in determining a proper rehabilitation strategy for a bridge approach pavement, including pavement structural design and LCCA.

The proposed process improvement will enable FDOT to develop a good management system for bridge approach pavements and make better M&R decisions for these pavements. The long-term benefit is reduced M&R frequency and life cycle cost at these bridge approach/departure pavements. Most importantly, the public can benefit from these changes in terms of reduction in delay time, accident risk, fuel consumption, vehicle wear and tear, and environmental impact that may all arise in M&R related work zones.

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APPENDIX A RESPONSES FROM VARIOUS STATE DOTS IN THE NATIONWIDE QUESTIONNAIRE SURVEY

In this appendix, the responses received from various state DOTs are presented for every question in the nationwide survey questionnaire. The states that the state DOT acronyms represent are shown in Table 3-1 of Chapter 3.

PART A: Extent of Asphalt Pavement Damage at Bridge Approaches and Departures

1. **Do you notice more distress or damage of the asphalt pavement adjacent to bridge approach/departure slabs than on regular asphalt pavement sections on highways in your state? See the picture below for an example of the pavement distress location we are researching.**

Responses:

- **Alabama Department of Transportation (ALDOT):** Yes
- **Alaska Department of Transportation & Public Facilities (DOT&PF)**: No
- **Arizona Department of Transportation (AZDOT):** Yes
- **California Department of Transportation (Caltrans):** Yes
- **Colorado Department of Transportation (CDOT):** No
- **Florida Department of Transportation (FDOT):** Yes
- **Georgia Department of Transportation (GDOT):** Yes
- **Hawaii Department of Transportation (HDOT):** Sometimes, mostly on old bridges.
- **Idaho Transportation Department (ITD):** No, it's the converse.
- **Illinois Department of Transportation (IDOT):** Yes
- **Iowa Department of Transportation (Iowa DOT):** Yes
- **Kentucky Transportation Cabinet (KYTC):** Yes, definitely an issue.
- **Louisiana Department of Transportation (LADOT):** Yes, The asphalt adjacent to the approach slabs might experience a little more distresses than regular sections but this is

probably due to constructability problems with the transition from roadway construction to bridge/approach slab construction.

- **Maryland Department of Transportation (Maryland DOT):** Yes
- **Michigan Department of Transportation (MiDOT):** Yes
- **Mississippi Department of Transportation (Mississippi DOT):** Yes, we notice more distresses in pavement adjacent to bridge end slabs than in regular pavement.
- **Missouri Department of Transportation (MODOT):** No
- **Minnesota Department of Transportation (MnDOT):** Yes
- **Montana Department of Transportation (MDT):** Yes
- **Nebraska Department of Roads (NDOR):** We have seen distress at a few isolated locations. Not widespread.
- **Nevada Department of Transportation (NDOT):** We notice more distress next to bridge approach slabs. Most bridges have concrete approach slabs next to the bridge and the asphalt or concrete pavement up to the approach slab.
- **New Mexico Department of Transportation (NMDOT):** Not in particular.
- **Ohio Department of Transportation (Ohio DOT):** Ohio has many asphalt surface pavement with rigid base. We call these "composite pavements". For the purpose of this survey, we assume you are interested in "flexible pavements". Ohio has not noticed any premature or dissimilar performance of flexible pavements adjacent to bridges.
- **Pennsylvania Department of Transportation (Penn DOT):** Yes
- **Rhode Island Department of Transportation (RIDOT):** No
- **South Carolina Department of Transportation (SCDOT):** Yes. This is a common issue.
- **South Dakota Department of Transportation (SDDOT):** Yes. We have actually been beefing up the section adjacent to the structure to help combat this problem.
- **Tennessee Department of Transportation (TDOT):** Yes. This is common.
- **Utah Department of Transportation (UDOT):** We have not really noticed this. We do have a bump quite often from the settlement of the approach slab or pavement relative to the bridge.
- **Virginia Department of Transportation (VDOT):** N/A
- **Washington Department of Transportation (WSDOT):** It depends on location. This is true for some routes but not all.
- **Wisconsin (WisDOT):** In general I would say no. we do not see this type of distress on a regular basis here in Wisconsin.
- **Oregon Department of Transportation (Oregon DOT):** No. However, we do have a number of bridges in our state that show more distresses and/or damage at the approaches/leaves than in the surrounding pavement.

2. **Roughly what percentage of asphalt pavements adjacent to bridge approach/departure slabs have showed more distresses than regular asphalt pavement sections on highways in your state? Please highlight one of the following options.**

Responses:

- **ALDOT:** 6-24%

- **DOT&PF:** 0% to 5%
- **AZDOT:** We do not know the percentage but have seen a lot. Typically, we design thicker pavement section next to bridge approaches.
- **Caltrans:** 25% to 50%
- **CDOT:** 6%-24%
- **FDOT:** 6%-24%
- **GDOT:** 6-24%
- **HDOT:** 6%-24%
- **ITD:** 0%-5%
- **IDOT:** 51% and more
- **Iowa DOT:** 25% to 50%
- **KYTC:** 51% and more
- **LADOT:** 51% and more
- **MDOT (Maryland):** 0%-5%
- **MiDOT:** 25% to 50%
- **MDOT (Mississippi):** 25% to 50%
- **MODOT:** 0%-5%
- **MnDOT:** 25% to 50%
- **ODOT (Ohio):** 0%-5%
- **MDT:** 25% to 50%
- **NDOR:** 0%-5%
- **NDOT:** 6%-24%
- **NMDOT:** 6%-24%
- **Penn DOT:** 6%-24%
- **RIDOT:** 0%-5%
- **SCDOT:** 25% to 50%
- **SDDOT:** 25% to 50%
- **TDOT:** 25% to 50%
- **UDOT:** 0%-5%
- **VDOT:** 6%-24%
- **WSDOT:** 0%-5%
- **WisDOT:** 0%-5%
- **ODOT:** 6%-24%

3. **Can you please describe the types of asphalt pavement distress you have observed adjacent to bridge approach and departure slabs?**

   Responses:

   - **ALDOT:** Raveling, pop-outs and pot holes at the interface of the bridge end slab and the asphalt pavement.
   - **DOT&PF**: Almost nothing other than occasional plow strikes and normal rutting.
   - **AZDOT:** Minor deformations, rutting and cracking.
   - **Caltrans:** Rutting, shoving, raveling, potholes, bleeding, flushing.

- **CDOT:** Occasional distresses as a result of poor compaction at the bridge approach and departure slabs.
- **FDOT:** Alligator cracking with lime rock base bleeding through the cracks. The alligator cracking is severe enough where the pavement is also exhibiting rutting in some cases.
- **GDOT:** Raveling, thin sections, rutting, cracking and pop outs.
- **HDOT:** The common pavement distresses include transverse, longitudinal and alligator cracking. Sometimes rutting is observed. It could be the result of improper compaction of the embankment backfill near the bridge abutment. Also, unsealed slab joint and cracks allow water to enter the pavement structure causing pumping and faulting to occur.
- **ITD:** Differential compaction between approach slab and roadway slab.
- **IDOT:** 1) Potholes and pumping due to dynamic loadings of trucks bouncing over the bridges and rundowns**.** 2) Bumps at broken pavement due to expansion and bouncing loads. 3) Settlement issues and expansion of pavements.
- **Iowa DOT**: Depression in the HMA pavement, causing an uneven surface / rough ride.
- **KYTC**: We have seen an increase in the asphalt at each end of the bridges, in my opinion it is from sub grade failures…it is difficult to get compaction so close to the abutments.
- **LADOT:** 1) Composite pavements where asphalt overlay thins as it approaches bridge; 2) Expansion joints at bridge approaches on composite pavements; 3) Rutting increase possible due to truck impact when roadway settles and bridge doesn't; 4) Approach slab settlement, movement and/or rocking. Many times a gap forms between the asphalt on the approach slab and the bridge end; 5) Dips/differential settlement due to future embankment consolidation or due to the loss of fines from lack of confinement around the bridge's end bents, fatigue cracking and pumping of fines, transverse/longitude cracking, etc.
- **MDOT (Maryland):** Minor settlement
- **MiDOT:** Fatigue cracking and rutting as a result of weak subbase.
- **MDOT (Mississippi):** With regards to the asphalt pavement itself, we have noticed increased rutting, cracking and even some swelling up next to the approach slabs.
- **MODOT:** Settlement is the primary concern.
- **MnDOT**: Bumps at the slabs and raveling of mixture.
- **MDT:** Among the distresses we have observed are: rutting/shoving, alligator cracking, some stripping.
- **NDOR**: We have had a few examples recently of failed HMA pavements at bridges in a sag. Failure was due to saturated subgrades. HMA pavements were generally built on compacted or stabilized subgrades without a granular drainage layer due to a scarcity of ledge rock in the state. Failures were addressed by the installation of a drainage system and replacement of the failed pavement (appr. 100').
- **NDOT:** Asphalt paving next to approach slabs have lateral and longitudinal cracking, with some settlement and rutting.
- **NMDOT:** Distress due to settlement of the approach roadway fill (for areas in which fill had to be brought in to raise grade).
- **ODOT (Ohio):** We have not observed anything of the sort.
- **Penn DOT:** Cracking and potholes.

- **RIDOT:** Mostly cracking.
- **SCDOT:** Raveling and stripping are most common failures on the Interstate. Rutting and Shoving also occur.
- **SDDOT:** Deformation and alligator cracking.
- **TDOT:** Settlement.
- **UDOT:** Settlement related impact damage if any.
- **VDOT:** Cracking (fatigue, joint), Potholes, Consolidation of underlying sub-structure, accelerated stripping in asphalt over approach slabs and Delamination's.
- **WSDOT:** Asphalt over concrete: delamination caused by compression failures of the underlying PCCP. In some cases, the asphalt delaminates off the distressed concrete at bridge ends or approach slabs. In other cases, the underlying concrete compresses against the bridge end or approach slab, cracks and eventually both the asphalt and concrete spall leaving potholes.
  Concrete surfaces: the concrete roadway abutting approach slabs or bridge ends often cracks and spalls due to compression.
  Full depth asphalt: asphalt pavement abutting approach slabs or bridge ends often cracks requiring patching.
- **WisDOT:** The types of distresses we might observe would be possible segregation from short passes or additional handwork, possibly a rough joint tying in to existing pavements
- **ODOT:** Distresses at these locations include rutting, fatigue cracking, and potholes.

4. **In the areas where you noticed distress or damage on the asphalt pavement, was there a significant difference in the asphalt thickness adjacent to the bridge approaches/departures compared to the rest of the roadway? If yes, please describe the differences.**

   Responses:
   - **ALDOT:** We began noticing this condition a few years back, at that time the bridge end slab were flush with the bridge deck and were not paved with asphalt. At that time, normal resurfacing project would feather the asphalt down to tie in at the bridge end slab. Thus resulting in thinner pavement at the interface with the bridge end slab. ALDOT bridge end slabs are a standard 20 ft in length and 9 nine in of reinforced concrete pavement.
     As I stated earlier, during resurfacing projects the contractor would typically feather the asphalt down to tie in at the bridge end slab. Example condition: The roadway pavement is 12 in of asphalt. The resurfacing operation calls for milling 2.0 in from the roadway and placing 3.0 in. The net change in the roadway profile is +1.0 in. The contractor must then transition the asphalt to the bridge end slab or the roadway will have a 1.0 in "bump" at the bridge end slab. After repeated resurfacing, the pavement at the bridge end slab could be as much as 3.0+ in thinner than the rest of the roadway.
   - **DOT&PF:** No
   - **AZDOT:** Yes
   - **Caltrans:** No
   - **CDOT:** No

- **FDOT:** Yes, the thickness was significantly less than the pavement further down the road. 4-6 *in* vs. 10+ *in*.
- **GDOT:** Yes, sometimes there is a difference in the thickness of the surface mix where contractors will feather down to tie in to the bridge rather than properly mill and inlay at the bridge.
- **HDOT:** No
- **ITD:** No
- **IDOT:** Yes, usually rundowns in this area are really thin.
- **Iowa DOT:** No
- **KYTC:** No
- **LADOT:** 1) Yes; often, there is significant difference due to overlay of existing concrete pavement and asphalt thins to match bridge. We also overlay the approach slab if road and/or approach have settled. 2) We have recently revised our standards to have a concrete approach slab with a 2 in asphalt overlay, hasn't been in place long enough to describe differences between this design and "older" designs. 3) It should all be the same; however, as mentioned above, there are some differences in the quality at the transitions due to small irregular areas that may need to be hand-worked.
- **MDOT (Maryland):** No
- **MiDOT:** No
- **MDOT (Mississippi):** In instances where there is asphalt pavement over the approach and departure slabs the asphalt thickness is generally less than the rest of the roadway. In cases where the asphalt pavement butts up to the approach slabs the pavement is usually the same thickness as the rest of the roadway.
- **MODOT:** No
- **MnDOT:** No, typically same structural thickness.
- **MDT:** In some cases, yes due to the mill/fill operations at the bridge to maintain grade then 200 ft back from the bridge end there's just an overlay with no milling so that makes for a weaker PMS section right at the bridge end.
- **NDOR:** No
- **NDOT:** No the asphalt thickness is typically the same.
- **NMDOT:** Yes. When approach roadway fill would settle, DOT maintenance forces would bring in more asphalt to correct grade.
- **ODOT (Ohio):** We match subgrade of surrounding pavement, thus there is not a difference in buildup.
- **Penn DOT:** No
- **RIDOT:** No
- **SCDOT**: Depends on the tie-down prior to the bridge, often existing pavement is tapered or butt jointed into the concrete pavement. The tapers often lead to thinner than normal surface courses which can lead to more fractured aggregate to obtain the required in place density. The saw cut or milled but joint can be improved with a bobcat (more mobile - transversely) milling head to provide a more uniform depth at the joint. However, there is a tendency for water to collect in this area due to inadequate drainage, which often is an issue with OGFC surfaces that leads to stripping and later raveling, top down and loss of bond from the bottom up.

- **SDDOT:** Majority is likely poor compaction in this area.
- **TDOT:** No
- **UDOT:** The distress again is usually related to settlement related damage. We normally run the same asphalt thickness up to the approach slab
- **VDOT:** We have not done enough forensics at these locations to answer.
- **WSDOT:** Not in areas where the approach slab is overlaid with HMA. Typically the asphalt is placed on an overlay anywhere from 2 to 3 in over the concrete.
  In areas where HMA abuts approach slabs and bridges the HMA is often not as thick as the rest of the roadway because overlays need to match the approach slab or bridge elevation preventing an increase in thickness near the bridge.
- **WisDOT:** Depending on the types of approaches, there are varying thicknesses. We try our best to stay within the Department specification requirements and pave multiple layers when necessary.
- **ODOT:** Generally, there is not a significant difference in asphalt thickness between the two areas.

PART B: Causes of Asphalt Pavement Damage at Bridge Approaches and Departures

5. What do you think are the potential causes of asphalt pavement distress adjacent to bridge approach/departure slabs in your state?

Responses:

- **ALDOT:** It is my opinion that the problem is twofold. One the thinner pavement section at the bridge end slab interface as previously discussed. Second the length of the bridge end slab is deficient. Depending on the length of the bridge, the numerous joints in the bridge deck can develop a harmonic bounce in the truck and when the truck is departing the bridge the harmonic bounce must be dissipated back to a smooth riding surface. I do not believe the 20 ft of the bridge end slab is enough length to dissipate the harmonic bounce and often it is amplified by the condition of the pavement at the interface with the asphalt roadway. Similarly, as a truck approaches the bridge if damage is present at the bridge end slab interface then the initial impact of the approach aids in producing the harmonic bounce associated with the numerous joints in the bridge.
- **DOT&PF:** Plows and studded tires.
- **AZDOT:** Material Changes from Rigid to Flexible.
- **Caltrans:** In the past, during design there was too little attention paid to including drainage features behind abutments. In the past, during construction, there was too little use of non-erodible base. Even when aggregate base was compacted to specified density (e.g. 95% of modified proctor) the base still failed under traffic and subsequently there was subsidence and uneven settlement under traffic.
- **CDOT:** Poor compaction at the time of construction
- **FDOT:** 1) Inadequate structural support (the asphalt isn't thick enough).2) Often the transition from the bridge to pavement is not level due to construction, settlement, or other factors. This creates a bump that generates a dynamic load which accelerated damage.

- **GDOT:** Inadequate or improperly placed asphalt mixture. Poor joint tie in leading to increased dynamic loading causing more damage to the pavement.
- **HDOT**: An expansion joint is used to allow for thermal changes that occur in the bridge and approach slab, improperly installed or poorly maintained join seal allow water infiltration and debris accumulation. This will cause distress to both bridge and the pavement.
- **ITD:** Drainage, density, compaction, workmanship, experience.
- **IDOT:** 1) Different expansion/contractions, trapped under pavement, profile over bridges rough causing trucks to bounce. 2) Expansion and contraction of bridges. 3) Grade settlements due to pavement expansion.
- **Iowa DOT:** The main factors are settlement adjacent to bridge approaches due to loss of fines and inadequate compaction of the subbase materials adjacent to the bridge approach. Once initial settlement occurs, the problem is amplified by the impact loads of heavy trucks going on and coming off the bridge. This often leads to additional distresses, such as rutting / distortion of the HMA.
- **KYTC:** Our bridges are being designed without approach and departure slabs.
- **LADOT:** 1) Rutting due to impact loads of trucks especially when road has settled or been overlaid and approach/departure grades at bridge do not match. 2) Thinning of asphalt overlay as mentioned above. 3) Soil conditions, settlement over time. 4) Future construction work performed after the bridge/approach slabs have been constructed. Hand worked asphalt areas that may be more prone to raveling. A lack of compaction in subsequent lifts.
- **MDOT (Maryland):** Differential settlement caused by insufficient compaction at the abutment.
- **MiDOT:** Weak base as a result of inadequate compaction.
- **MDOT (Mississippi):** The two main causes of pavement distresses near bridge ends are inadequate compaction efforts of the base near the bridge ends and the bumping of the pavement from the movement of the approach/departure slabs over time.
- **MODOT:** Settlement.
- **MnDOT:** Contractor workmanship.
- **MDT:** We feel one of the causes is the weaker section. Another cause is poor compaction under the plant mix right at the bridge end. It is very hard to get the material at the bridge end compacted to the same density as the native soils adjacent to the bridge end.
- **NDOR:** Saturated subgrade.
- **NDOT:** Drainage issues, heavy truck traffic on some roadways, poor compaction of the subgrade and aggregate base next to the approach slab.
- **NMDOT:** Most of the time it is due to settlement of the approach roadway fill or poor drainage resulting in washout of fill material under the concrete approach slab causing settlement.
- **ODOT (Ohio):** N/A
- **Penn DOT:** Compaction of the subbase, and asphalt layers.
- **RIDOT:** Time and Traffic.

- **SCDOT**: Is there enough tack to bond to existing layers, and was the tack broke prior to placing the mix (in a hurry to begin paving)?
  The tied-own itself with the amount of lute-hand work involved, and the likelihood of dealing with the first of last load of the day or night having temperature segregation. Difficulty in compacting and or getting equipment into the area. Differing subgrade conditions.
- **SDDOT:** Majority is likely poor compaction in this area.
- **TDOT:** Either compaction (i.e., lack thereof) of aggregate base materials aka bridge backfill materials or compaction of supporting materials underneath bridge approach slabs, when applicable.
- **UDOT:** Differential settlement between the pavement and bridge structure causing impact loads.
- **VDOT:** Drainage issues, trapping water between the approach slab and shoulder, typically our under drains do not reach to the extents of the bridge decks, Insufficient compaction of the subgrade at the abutments, Poor tie-ins and bonding on maintenance overlays at the bridge deck
- **WSDOT:** Compression failures of the underlying concrete. For full depth asphalt at bridge ends or approach slabs the failure often results from <u>thin</u> asphalt structure.
- **WisDOT:** We don't typically see this type of distress. I would guess that it is a pavement thickness layer issue (too thin), possibly too much handwork if a crew is trying to feather in the material, etc.
- **ODOT:** Potential causes of pavement distress at bridge approaches include a saturated and/or weak subgrade, moisture infiltration into the pavement (stripping), and differential loading responses between asphalt section and bridge ends. Occasionally, the bridge approaches have been evaluated as structurally deficient.

PART C: M&R Strategies for Asphalt Pavements at Bridge Approaches and Departures

6. Are M&R activities more frequent on asphalt pavement sections at bridge approaches/departures than on regular asphalt pavement sections on highways in your state? Please explain the reasons.

Responses:

- **ALDOT:** They are about the same as typical roadway distresses, however, you will typically have distress at a majority of the bridge ends. The frequencies of maintenance activities vary with the method of rehabilitation. If cold patch material is used the repair may last for a very short time under traffic. Hot placed patching material may last a little longer. The longest rehabilitation activity is an extra depth patch repair that encompasses both lanes is large enough to cover area outside of the failed pavement.
- **DOT&PF:** No
- **AZDOT:** Typically, No. But depends on situation.
- **Caltrans:** Yes, because asphalt and concrete are dissimilar materials and don't behave the same when expanding and contracting. Consequently the asphalt pavement against a concrete abutment tends to develop a hump at the interface. Vehicle dynamics due to rough pavement or a rough bridge deck may cause load-induced distress at the approach

slabs. Maintenance forces repairing an approach slab may use substandard materials and the repair will have a brief service life.

- **CDOT:** No
- **FDOT:** Yes, patches have to be placed until the section gets resurfaced.
- **GDOT:** Yes. Because of the earlier issues detailed in previous questions, the asphalt at the bridge tie is does not perform as well as asphalt placed in other locations.
- **HDOT:** It might affect the maintenance cycle of the pavement along the older bridges. But rarely affect the rehabilitation schedule of roadways.
- **ITD:** No, actually it's the converse.
- **IDOT:** Yes potholes repair**.**
- **Iowa DOT:** Yes. If the settlement problem near bridge approach occurs, it will lead to required maintenance earlier than for normal deterioration of the rest of the pavement section.
- **KYTC:** We are continually patching the bridge ends…no end in sight.
- **LADOT:** 1) Extremely more frequent. Asphalt ravels or ruts where it thins approaching bridges; mostly composite pavements; Composite pavements at expansion joints. The 3 in expansion joint in concrete pavement can't be successfully transferred through asphalt overlay. Preformed devices won't last or fit properly in asphalt over concrete expansion joint. 2) Yes and No, it depends upon the location of the roadway. 3) A little more frequent due to the nature of the transition from a roadway structure to a bridge, and depending on the roadway pavement structure, the types of distresses and potential causes may vary a good bit.
- **MDOT (Maryland):** Yes, just to add some wedge/level to bring the surface to the same level as the bridge when settlement occurs.
- **MiDOT:** Yes, due to the weak base and the need for reactive maintenance.
- **MDOT (Mississippi):** No, not usually. Unless the pavement is in dire need of immediate repair the pavement will not get repaired until the surrounding roadway receives an overlay or a mill and overlay.
- **MODOT:** No
- **MnDOT:** No
- **MDT:** Yes, due to the distresses, maintenance does more frequently have to deal with these issues as the bridge ends. The reasons would be the same as #5 above.
- **NDOR:** Only slightly. Any amount of rutting will lead to a bump at the rigid approach section which sometimes needs to be smoothed with an HMA maintenance patch until the next resurfacing addresses it.
- **NDOT:** No typically the pavements next to bridge approaches are repaired when a pavement preservation project is completed on the roadway. More repairs may be needed next to the bridge approach but all work is typically completed with the pavement preservation project. If work is required before a pavement preservation project then it is typically done by District forces with a level of repair to get it to last until the next project.
- **NMDOT:** M&R activities are more frequent on regular asphalt pavement sections on highways than at bridge approaches because we have approximately 11,000 mi of roadway versus only 3000 bridges in NM.
- **ODOT (Ohio):** N/A

- **Penn DOT:** On average about the time the distress at the bridge approach or departure requires a maintenance treatment we are also starting to see pavement distress at the centerline or edge line of the pavement.
- **RIDOT:** No
- **SCDOT**: I would say yes; due to the cold joint between the two different pavement types.
- **SDDOT:** Yes, due to maintaining a smooth transition on and off the bridges.
- **TDOT:** We currently do not quantify how often rehab activities occur at bridge ends versus regular pavement repairs.
- **UDOT:** I think they are a bit more but we have nothing to support this.
- **VDOT:** Patching quantities are probably higher due to the distresses noted above.
- **WSDOT:** Not necessarily.
- **WisDOT:** No, not on our main infrastructures, local government agencies have not expressed any concerns that we are aware of.
- **ODOT:** At times, additional maintenance activities such as leveling or patching may be required more frequently. In regards to rehabilitation, bridge approaches are typically evaluated at the same time the mainline pavement is unless otherwise needed.

7. Are there any special M&R strategies and guidelines for defective asphalt pavement sections adjacent to bridge approach/departure slabs in your state?

Responses:

- **ALDOT:** None that I am aware of for routine maintenance. Resurfacing and rehabilitation projects tend to address specific repairs for these areas.
- **DOT&PF:** No, but occasional patching may be done due to studded tire wear to match grade (pavement to bridge).
- **AZDOT:** We design thicker pavement section next to bridge approaches.
- **Caltrans:** See Section 51-5 “Approach Slabs” of the 2015 Standard Specifications [http://www.dot.ca.gov/hq/esc/oe/construction_contract_standards/std_specs/2015_StdSpecs/2015_StdSpecs.pdf]
- **CDOT:** No
- **FDOT:** We’ve addressed these issues in the past with reconstruction or deep milling/resurfacing.
- **GDOT:** We use patching with both hot mix asphaltic concrete and also cold placed mastic type patching material.
- **HDOT:** None
- **ITD:** Simple remove and replace.
- **IDOT: 1)** No- typical amazing to fix potholes and bump grinding. Sometimes diamond girding. 2) 4-6 ft expansion patches. 3) Diamond girding smoothness in decks at approaches. 3) Utilizing bituminous expansion patches.
- **Iowa DOT:** In most situations, the affected area is milled (to level out the surface) and uniform thickness of HMA is placed and compacted.
- **KYTC:** None
- **LADOT:** 1) No! On I-20 in Northeast Louisiana, we are currently performing a four parish/county project to primarily mill and overlay bridge ends.2) Full depth patching if

base failures, flow able fill to underseal the area (e.g., voids under the approach slab, sealing off gaps in the abutment, etc.), partial depth patching and filling pot holes with cold mix, leveling with hot mix.

- **MDOT(Maryland):** No
- **MiDOT:** We typically use a concrete approach slab but have situations where HMA was used.
- **MDOT (Mississippi):** In most all cases when a project is let to mill and overlay a section of road which includes bridges, the pavement is milled at a deeper depth than just the one lift the project requires. This is done to allow two or more lifts of asphalt to be laid up next to the approach/departure slabs.
- **MODOT:** No
- **MnDOT:** No
- **MDT:** We deal with them on a case by case basis. Our maintenance forces monitor their respective areas and when the bridge ends get bad enough, maintenance will usually perform one of the following measures:
    a) Blade patch
    b) Mill/fill
    c) Use rut filling mastic with ½ in rocks. This is very durable and it is also self-leveling which makes for a smooth, quality, lasting fix.
- **NDOR:** The few failures we have had have been corrected by installing transverse pipe underdrains in granular trenches and using a drained foundation course beneath a rebuilt pavement (approximately. 100').
- **NDOT:** No. NDOT utilizes the same strategies and guidelines as it does for other pavement maintenance.
- **NMDOT:** On some occasions we will jack up the approaches by injecting cementitious grout or polyurethane into the subgrade/fill to correct the grade.
- **ODOT (Ohio):** N/A
- **Penn DOT:** Not at this time.
- **RIDOT:** No
- **SCDOT**: Not specifically at this time. We are looking into and have tried several mastic repair materials for smaller fixes. We have also been experimenting with termination of OGFC prior to the bridge decks so that the transition of the material is easier to work with and avoids trapping water. Lastly, we try to control cross slope and drainage such that we avoid trapping water in the OGFC layer. For non-interstate routes that do not include OGFC, we try to identify if the problem is being caused in the surface or deeper in the pavement structure and tailor the fix to the problem.
- **SDDOT:** None that I'm aware of.
- **TDOT:** In the event of settled approach slabs, slab jacking work has been used to repair the deficiency.
- **UDOT:** No
- **VDOT:** Not at this time.
- **WSDOT:** Provide sufficient asphalt depth to provide a long lasting pavement for full depth asphalt sections. For asphalt over concrete, place asphalt on sound concrete, provide expansion joints (saw cut relief cuts, allow expansion between underlying concrete (concrete pavement or approach slabs or bridge ends).

- **WisDOT:** N/A
- **ODOT:** Bridge approaches and mainline pavement are evaluated according to the same design service life during a rehabilitation cycle unless reconstruction is needed. When reconstruction is needed (i.e., structurally deficient, bridge replacement), the bridge approaches are designed to a higher service life.

8. Please provide other comments regarding the performance of asphalt pavements adjacent to bridge approach/departure slabs in your state.

Responses:

- **ALDOT:** As discussed earlier, we observed the trend of the contractor feathering down the asphalt to tie to the bridge end slab interface. Some years back we began modifying the design for the bridge end slab location during initial construction. The modification is to place the bridge end slab approximately 3.00 in below the bridge deck. This allows for a minimum upper binder and wearing surface to be placed on top of the bridge end slab or for the placement of a wearing surface and a polymer modified open graded friction course, typically we do not pave over the bridge deck. However, on some projects the polymer modified open graded friction course is placed on top of the bridge deck. Also during resurfacing and rehabilitation projects, extra depth milling is incorporated at the bridge end slab/pavement interface. Although the pavement may be thinner at this location the extra depth milling allows for removal and replacement of a greater quantity of "older" asphalt and replacement with "new" high quality material. In some cases, full depth reconstruction is utilized in these locations in an attempt to provide significant structure to withstand the truck traffic loading.
- **DOT&PF:** None
- **AZDOT:** None
- **Caltrans:** see the following documents.
http://www.dot.ca.gov/hq/esc/earthquake_engineering/research_reports_site/STAP_Research_Notes/Research_Note_Approach%20Slab.pdf
NCHRP Synthesis 234
http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4147-S.pdf
- **CDOT:** It's important to achieve proper compaction of asphalt pavements at bridge approach / departures – sometimes, this mean adjusting the roller pattern.
- **FDOT:** N/A
- **GDOT:** At times, contractors fail to remove the wedge that is placed at the bridge tie in when the roadway was milled and prior to resurfacing. When the wedge is left in place, the resurfacing results in a very thin lift of asphalt mix at the bridge tie in. Over time, the mix will ravel out leaving a significant bump that results in further deterioration of the asphalt in these locations.
- **HDOT:** None
- **ITD:** N/A
- **IDOT: 1)** Need a spec on backfilling abutments to get compaction to reduce settling of the approaches, not to engineer's satisfaction. 2) Design of approach slabs is critical. Many times approach pavement settling caused extreme roughness and bouncing loads.

- **Iowa DOT:** No additional comments.
- **KYTC:** It is my opinion the designers need to rethink the approach and departure slabs that seemed to work the best.
- **LADOT:** whether it's new construction of a bridge and roadway, the type of roadway pavement structure versus the approach slab, proper drainage of the approach slab, good confinement around the end abutment, etc.
- **MDOT (Maryland):** N/A
- **MiDOT:** There is a lot of impact loading that occurs in these areas and the HMA and weak base cannot resist these forces without some deformation.
- **MDOT (Mississippi):** To alleviate the movement of the bridge end slabs, the slabs will sometimes be injected with expandable foam to raise them to the correct elevation and prevent them from moving.
- **MODOT:** N/A
- **MnDOT:** N/A
- **MDT:** To counteract future issues, we recently developed a 30-year bridge end design memo.
  http://www.mdt.mt.gov/other/webdata/external/cadd/design_memos/2015-04-29_30_yr_bridge_ends.pdf
- **NDOR:** N/A
- **NDOT:** Because Nevada has a mild and dry climate we do not have as many issues as other states with our pavements. The approach pavement usually last as long as the rest of the pavement but may have additional distresses.
- **NMDOT:** N/A
- **ODOT (Ohio):** Ohio DOT does see differences in performance for rigid pavement near bridges, and thus once overlayed with asphalt this issue continues. Our reason for this is based on our opinion that pressure relief placed near the bridges (by design) to protect back walls eliminates the compression in the concrete and allows for intermediate slab cracks to deteriorate.
- **Penn DOT:** N/A
- **RIDOT:** The performance of pavements adjacent to bridge decks is similar to the performance elsewhere.
- **SCDOT:** They are always suspect to be one of the first signs of pavement distress.
- **SDDOT:** The attached "Bridge Approach Detail" is this DOT's standard practice when replacing adjacent asphalt.
- **TDOT:** On most occasions with failures at bridge ends, failures can be linked to poor construction such as low compaction of materials; either base, backfill, and asphalt materials or supporting materials underneath approach slabs. This can often be the result of bridges and pavements being built either by separate contracts or by separate contractors under the same prime contract, but can be remedied with proper field inspection.
- **UDOT:** Quite often the differential settlement problem is handled with concrete approach slabs that can be leveled overtime with pumpable material (either a grout or foam).
- **VDOT:** N/A
- **WSDOT:** N/A
- **WisDOT:** So far we are not having pavement performance concerns at these locations.

- **ODOT:** N/A

APPENDIX B RESPONSES FROM VARIOUS STATE DOTS ON REHABILITATION TECHNIQUES FOR INADEQUATE ASPHALT PAVEMENT STRUCTURES

1. *If you are experiencing alligator cracking due to inadequate pavement structure or inadequate asphalt pavement thickness, are there any methods or techniques specified by your agency, or most frequently used by contractors, as a permanent repair for the pavement, if the vertical alignment of the roadway could not be changed?*

   Responses:

   - **Alaska DOT:** We do not address fatigue cracking directly as the reason to perform repairs. Cracking has not been a major concern for us to date. When we resurface our roads (usually overlay, mill/fill, or reclaim) it will fix any cracking distresses that might have been there.
   - **Indiana DOT:** If the vertical alignment of the roadway could not be changed, then cement stabilized or asphalt emulsion stabilized full-depth reclamation techniques can be used to reconstruct the pavement base.
   - **Michigan DOT:** We seldom, if ever, experiencing fatigue cracking as result of inadequate base.
   - **New York DOT:** For small, localized areas of alligator cracking, Maintenance crews would probably saw cut around edges to sound pavement and excavate distressed asphalt to sound material, then fill and compact localized patch (2-4 year life). If larger scale distress over a longer segment of roadway, then it may depend on if it is full depth asphalt or composite (asphalt over jointed plane concrete pavement). If full depth we most probably will do a mill & fill, milling down 4 in or more to sound material, the build back up to existing elevation. If subsurface drainage appears to be a contributing factor, then edge drains may be installed to help improve the subbase & base materials from further accelerated damage. If edge drains are already in place, then flush and clean them. (8-12 year service life). Many of our Interstate highways are composite pavement over 60 year old (self rubblizing) jointed plane concrete pavement and alligator cracking over these self rubblized areas does become a predominant distress for longer segments. In these cases if we're looking to do just minimal preservation type treatments, then we'll mill off the asphalt for the segment length and expose the concrete. Distressed (self rubblized) sections of concrete are easily identified and removed, sometimes excavating and replacing some of the base materials in these localized areas. We have done both localized asphalt patching/paving in place of these excavated areas of exposed concrete pavement, or replaced in kind with concrete, depending on temporary traffic control and lane restrictions. Once repairs to the PPC pavement are complete, then overlay with asphalt. Same comments with edge drain install if necessary. (6-8 years service life)…shorter service life because we have witnessed that once the 60 yr old concrete pavement starts to go, then it tends to accelerate the rate of distresses. Long term on these composite pavement sections, we would probably mill up the asphalt and do a crack and seat on the existing PPC, then a complete full depth overlay…but that will increase roadway elevation. (10-15 years service life)
   - **Missouri DOT:** Mill/Fill Techniques – Cold milling was performed for the three methods below so that the profile did not change: (1) Used Fiber Reinforced Asphalt

using FORTI-FI high tensile strength fibers in asphalt mixtures. (2) Used Krayton Polymer highly polymerized asphalt binder in the asphalt mixtures. (3) Used a Pavement Reinforcement Grid under an asphalt mixture. Thicker Mill/Fill Techniques: (1) Mill 5 or 6 in and replace with 5 in or 6 in PCCP with 6 ft x 6 ft joint spacing. (2) Deep Injection using polyurethane to stabilize subgrade; then mill/fill with HMA or PCCP. (3) (Pre-mill as necessary) Full Depth Reclamation and cover with HMA.

- **Washington DOT:** First, we would verify that the alligator cracking is completely through the bound layers. We have found that what often appears to be full depth cracking only extends to the interface between the top lift of HMA and the underlying layers. Assuming that the cracks are all of the way through the bound layers we would consider the following alternatives: If the alligator cracking is not widespread we would consider full depth repair of the alligator cracked areas and mill and inlay the remaining pavement. The expected service life of this type of repair would be 10 - 20 years depending on which part of Washington it was located. Remove the existing pavement and underlying base and replace with a new long life section. We would design the new pavement structure for 50 years knowing that the surface would need periodic renewal in the form of milling and inlaying. We would consider full depth reclamation but this is not a common practice for WSDOT. Most of our urban roadways have too high of a traffic volume roadways to make FDR feasible and we use different techniques (CIR, cushion course etc.) on our lower volume rural roadways where the grade elevation is not constrained. With FDR we would need to remove some of the material to ensure the grade is not changed. We would design the new pavement structure for 50 years knowing that the surface would need periodic renewal in the form of milling and inlaying. We would use life cycle cost analysis to determine which of these methods is most cost effective. If we had a constrained budget, we would consider a thick mill and inlay (3 – 4 in) if we could get 10 to 15 years of additional pavement life. We would budget for a permanent solution the next time the pavement needed rehabilitation.
- **Rhode Island DOT:** The recommended approach, if a structural deficiency is confirmed by the FWD/ELMOD results, should be the replacement of the asphaltic layer and check if the aggregate base material is suitable to replace with the appropriate thickness layers according to the design period evaluated. Another options such as the use of a lean concrete base or full depth reclamation could be considered, depending of circumstances.
- **Colorado DOT:** In response to your survey, the Colorado Department of Transportation has applied a couple different strategies to handle fatigue cracking with inadequate structure. The most common way CDOT handles this issue is by full-depth removal of the area affected area and replacing with the same thickness of HMA. The pavement designer will evaluate the life of this type of treatment and will justify why the typical design life can't be achieved. These full-depth patches can have a service life of up to 15 years. If it is a large area, the CDOT designer will use a "functional overlay" and will mention that this is not a permanent repair and the functional overlay is expected to last for XX years. Each project is different therefore, functional overlays can a service life from 5 to 12 years. On a couple of CDOT projects, we have milled the surface down about three in, placed a thin (1 in or less) HMA leveling course, placed a geogrid, and then a 2 in overlay. This process is new to CDOT and we have not developed a design process for this situation. The pilot projects are performing as intended. They show very little to no distress with the pavement expected to meet 10 to 14 years of service life.

- **Nevada DOT:** In two phases we might address the distress as described: First we would remove and patch full depth if the extent of the distress was not too great. If more extensive, we might pulverize the existing surface and some of the aggregate base, remove a portion to lower the compacted profile, treat with 2% cement, compact and overlay with 3-4 in of new pavement. 1-2 years for the first fix and 12-15 years for the second strategy.
- **Georgia DOT:** Not really. If this is occurring on a typical resurfacing project, we will normally mark and repair the most severely damaged areas using deep patching. But eventually, the road will need to be either reconstructed or another process such as FDR and place enough asphalt pavement on this new base to account for traffic loading.
- **Kansas DOT:** The Kansas Department of Transportation has a little experience with the situation you describe. The technique we have employed for an inadequate asphalt pavement thickness where the vertical alignment cannot be raised is a white-topping. That is, we milled out existing asphalt (6 in) and replaced it with concrete (6 in) cut into fairly small slabs (6 ft x 6 ft). A sample picture is attached. This actions has worked fairly well for us where we had old, thick (but inadequate) asphalt sections. We placed these on interstate sections about 5 years ago and have good performance so far. We expect 15 or more years out of these sections.
- **California DOT:** See pages 3-2 to 3-5 of the maintenance technical advisory guide [http://www.dot.ca.gov/hq/maint/FPMTAGChapter3-TreatmentSelection.pdf]; See page 12-6 at http://www.dot.ca.gov/hq/maint/FPMTAGChapter12_5-28-09Final.pdf; See pages 20 and 149 of the LCCA Manual at http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_Docs/LCCA_25CA_Manual_Final_Aug_1_2013_v2.pdf
- **Florida DOT:** In Florida, we experience predominately top down cracking as our main deficiency and the predominant rehabilitation method is to mill (depth to match cracks) and resurface. The majority of the resurfacing projects are budgeted and scheduled to begin before alligator cracking occurs. Alligator cracking typically signals a pavement that is way over due for a resurfacing or there is a base issue. The EOR or Pavement design engineer should request a core in the area in question. The core will confirm the existing cross-section and the EOR can do a quick analysis to see if the pavement design is adequate. If the pavement does not meet our standards, the EOR can at other base materials with a higher structural number or see if the elevation would allow for a thicker pavement. Our methods and techniques are presented in the Flexible Pavement Design Manual linked below. http://www.fdot.gov/roadway/pm/pcs/flexiblepavementmanual.pdf
- **Michigan DOT:** We seldom, if ever, experience fatigue alligator cracking as a result of inadequate base.

2. What are the typical or expected service lives of pavements repaired by the methods or techniques mentioned in the answers to the question above?

Responses:

- **Indiana DOT:** The reconstructed pavement base, if properly compacted and properly drained, should perform for 20+ years.

- **Missouri DOT:** Expect 7 to 12 years out of the Mill/Fill Techniques. Expect 12 to 20 years out of Thicker Mill/Fill Techniques.
- **Rhode Island DOT:** The typical pavement design period for this type of evaluations is 20 years. But, the design period could be changed to 10 or 12 years according to available funding and project scope.
- **Florida DOT:** New construction, reconstruction and resurfacing experience on average: Open Graded Friction Courses (OGFC) 13 years and Dense Graded Friction Course (DGFC) are lasting around 18 years.
- **Georgia DOT:** For those with deep patching placed on a resurfacing project, we hope to get another ~ 10 years. For a FDR project, the normal design life would be 20 years with surface layer replacement after 12 – 14 years.
- **Michigan DOT:** N/A.
- **New York DOT:** See above response.
- **Washington DOT:** See above response.
- **Colorado DOT:** See above response.
- **Nevada DOT:** See above response.
- **Kansas DOT:** See above response.

3. Is there any written rehabilitation guidelines used by your state DOT for asphalt pavement with insufficient structural capacity? If yes, could you send us the link of the guide?

Responses:

- **Colorado DOT:** CDOT does not have a written rehabilitation guideline for these projects. We require our HMA rehabilitation projects to have a minimum design life of 10 years. How the designer gets there is the million dollar question. When they can't make 10 years, the designer calculates the years at which the best design hits the threshold distress. He then states that this design is a functional design with an anticipated life of X years. https://www.codot.gov/business/designsupport/matgeo/manuals/pdm/2017-m-e-pavement-design-manual
- **Washington DOT:** Our pavement design requirements are contained in the WSDOT Pavement Policy. The WSDOT Pavement Policy is not specific to asphalt pavement with insufficient structural capacity but it is what we follow on all of our pavement designs. https://www.wsdot.wa.gov/NR/rdonlyres/EF9AAC9E-6323-4B09-A3D1-DD2E2C905D02/0/WSDOTPavementPolicyJune2015.pdf
- **New York DOT:** Please check our comprehensive pavement design manual. https://www.dot.ny.gov/divisions/engineering/design/dqab/cpdm

APPENDIX C RESPONSES OF FOLLOW-UP SURVEY ON REHABILITATION TECHNIQUES FOR BRIDGE APPROACH/DEPARTURE ASPHALT PAVEMENTS

1. Last time, you sent us an attached file "bridge approach detail" (standard practice when replacing asphalt pavement in bridge approaches). Could you tell us the reference of the attached file?

Responses:

- **South Dakota DOT:** Generally maintenance crews will patch or fill in cracks/ruts and grind down bumps to smooth out the profile at the bridge approaches as needed. I don't know if there is a certain set of guidelines they follow, probably just by monitoring the highway and routine checks. If the pavement distress continues to be a problem despite continuous maintenance, my office looks at providing a more permanent form of mitigation with the thickened approach sections. Most of the issues at bridge approaches are due to impact loading from heavy traffic (semi-trucks) and an under-designed surfacing section. The detail calls for the old surfacing section to be removed and a thicker/stronger section be placed back. The section is spread out to reduce the likelihood of bumps forming at the bridge ends. We have modified the detail and now require that 18 in of material be removed from the approaches and we replace with 6 in asphalt concrete and 12 in Base Course over the MSE Fabric (A new Micro-station file of the detail is attached.

2. Last time, you mentioned that "We use patching with both hot mix asphaltic concrete and also cold placed mastic type patching material". Could you tell us the typical depths for hot patching and cold patching at bridge approach pavement sections? Is there a rule of thumb (or, guideline, manual) for determining the depth of patching and conducting the patching methods for bridge approach pavements? Regarding to your responses, "compared to the regular roadway, the asphalt thickness adjacent to bridge approaches/departures is relatively thinner". Could you tell us the typical difference of surface layer thickness between bridge approach pavement sections and the adjacent roadway?

Responses:

- **Georgia DOT:** I can't really provide you a typical other than it is normally through the entire surface layer which is ~ 1 -2 in. Again, this is a variable depth that is related to the contractor trying to tie in to the bridge when paving. Also, we sometimes place thin overlays ~ 1- 1-1/2 in over the concrete approach slab on many projects but due to the nature of paving operations, if not milled, the thickness of the surface layers vary at bridge ends due to the tie in requirement.

3. Is there a rule of thumb (or guideline, manual) for determining the thickness of patching/milling & resurfacing for bridge approach pavements? Based on your knowledge, what is the typical/normal overlay thickness for bridge approach pavement in your state? Is there any special treatments for bridge approach pavement maintenance that are different from regular pavements?

Responses:

- **Georgia DOT:** 1. Georgia normally mills the required thickness for the surface layer we are replacing. It is normally 1 in – 2 in as Shelia has stated. This is for standard approach slabs and recessed. We have two general types of approach slabs in Georgia. One is the standard approach that we pave up to. The second is a recessed approach slab that allows us to pave over it in case of any settling. The recessed approach typically allows up to 3 ¼ in of hot mix placement. 2. On new construction for recessed approach slabs 3 ¼ in. We normally try not to overlay our standard approaches and do not have a typical overlay thickness.   If the approach slab has settled it could vary. I have seen anywhere from 1 - 4+ in over them. 3. Not that I am aware of.

4. Last time, you mentioned that "The longest rehabilitation activity is an extra depth patch repair that encompasses both lanes that are large enough to cover area outside of the failed pavement". Could you tell us what are the typical depths for extra depth patching and normal patching. When to choose the extra depth patching repair methods instead of normal patching?

Responses:

- **Alabama DOT:** (1) Normal maintenance patching ranges in depth from 2 to 4 in. Extra depth patching is more with respect to the total pavement thickness and the depth of cracking as observed by taking cores in the distressed area. Extra depth patching normally is determined by the crack depth of the cores and the underlying asphalt material. In the past in some locations we have included a very rich liquid bituminous layer for crack mitigation, in this case if that material is observed in the cores, then the depth is removal would be limited to a maximum removal that would not disturb the rich bottom layer. (2) The choice whether to use normal or extra depth patching is dependent on the condition of the cores and the depth of cracking observed in the cores. It is our intent to remove as much of the cracking as is possible.

5. Regarding your response, "Resurfacing and rehabilitation projects tend to address specific for these areas (asphalt pavement sections adjacent to bridge approach/departure slabs)." Did your state have the manual about resurfacing design? When will your state choose to milling & resurfacing method instead of patching for bridge approach pavement sections? And, is there a rule of thumb for determining the depth of milling and resurfacing?

Responses:

- **Alabama DOT:** First asphalt pavement sections adjacent to bridge approach/departure slabs. Typically our bridge end slabs are 20 ft in length limited to the roadway width and 9 in thick. The problem then becomes how do you place an asphalt shoulder 2, 4, 6, 8, or 10 ft in width adjacent to the bridge end slab nine in thick and 20 ft in length. We have approached our Bridge Bureau and requested that where possible to design the bridge end slab from front slope to front slope to eliminate this problem. A recommendation you may need to make to FDOT and investigate just how many bridge end slabs they currently have that meet this same criteria. Second, as I stated before, a few years back we started lowering the bridge end slab so that asphalt could be placed on top of the bridge end slab for a smooth transition to the bridge. In this case the bridge end slab would be addressed with resurfacing projects. The typical depth below profile for the bridge end slabs is 3 in. This allows us two options during resurfacing. The wearing surface is normally 2 in and a 1 in Open Graded Friction Coarse (OGFC). This allows for resurfacing project that Micro mill and replace the OGFC or a resurfacing project that would remove the wearing surface and OGFC. If distresses are observed between resurfacing cycles, the local District can utilize their State Maintenance forces and/or a purchase order to mill and patch bridge end slab distresses along with localized roadway distresses. This is a routine Maintenance function. The rule of thumb for determining the depth of milling for a resurfacing project is normally based on the pavement condition survey, Falling Weight Deflectometer (FWD) testing and cores taken from the roadway. Pavement condition survey will give you the percentage of distresses and the severity level. FWD testing will determine if additional structure is required for future traffic loading. Pavement cores reflect the severity and depth of the cracks. Milling depth are typically set to remove the majority of the cracking. Replacement build-up is based on milling removal and/or the need for additional structure.

6. In the end, you mentioned that "In some cases, full depth reconstruction is utilized in these locations (bridge end slab/pavement interface) in an attempt to provide significant structure to withstand the truck traffic loading." Could you tell us what are the decision criteria for selecting the full depth reconstruction to address the bridge approach pavement distresses? Did your state have the guideline for implementing full depth reconstruction?

Responses:

- **Alabama DOT:** Typically if the condition of the roadway requires reconstruction, then bridge end slabs are reconstructed with the roadway. Some projects may require raising the bridge to meet an increased profile elevation, bridge end slabs are typically reconstructed at this time even if the roadway is a normal resurfacing project.

7. Last time, you mentioned that "In most cases when a project is let to mill and overlay a sections of road which includes bridges, the pavement is milled at a deeper depth than just the one lift the project requires. This is done to allow two or more lifts of asphalt to be laid up next to the approach/departure slabs". Could you tell us what are the typical overlay thickness for bridge approach pavement sections and the control section? Is there a guideline (or manual, or a rule of thumb) to determine the specific milling & overlay design for bridge approach pavement?

Responses:

- **Mississippi DOT:** Usually the asphalt is milled approximately 3-4 in at the bridge ends to allow for two lifts of asphalt each around 1.5-2 in where the top lift will match whatever the adjacent top lift is required to be as per the project’s contract. I haven’t been able to find any official guidelines for this as districts in MS tackle this process differently but generally its what I just stated. If anything different happens then it will be spelled out in the specific project’s contract.

8. Last time, you mentioned that "In your state, full depth asphalt pavement sections would be provided to keep a long lasting pavement service life for bridge approaches". Could you tell us the typical thickness for full depth asphalt pavement? Is there a manual, guideline or rule of *thumb about decision criteria for implementing full-depth asphalt pavement at bridge approaches? Regarding to your response, "The failure of bridge approach pavement (adjacent to approach slabs) is due to thin asphalt pavement structure". Could you tell us the typical surface layer thickness for "thin asphalt pavement"?*

Responses:

- **Washington DOT:** Here is a link to WSDOT's Pavement Policy. Within it, you will find HMA pavement depths for various ESAL levels. WSDOT designs for a 50-year pavement life (long life pavement life) and provides for periodic rehabilitation. Pavement depths at bridge ends are often based on the performance of adjacent HMA sections. If the pavement is functioning well, even at a lesser depth, WSDOT will provide the same depth at the bridge end. There are some cases at bridge ends where the depth was insufficient from the start to an increase in depth would be warranted. The thickness will depend on the roadway ESALs. Thin pavements are those that are designed for a 20 or 30-year design.

9. *Are there any special M&R strategies and guidelines for defective asphalt pavement sections adjacent to bridge approach/departure slabs in your state?*

Responses:

- **Montana DOT:** There are three options for bridge end treatments: (1) 30-year bridge end treatment: this is intended to alleviate bridge end distress using a 30-year design life of the pavement system where existing bridges will be reconstructed. (2) Minor bridge end treatment: this is also intended to alleviate bridge end distress and allows for future milling & resurfacing operations. If the roadway within 100 ft of the bridge ends of the bridge ends is showing increased signs of distress compared with the overall project roadway condition, mill an additional 0.2 ft (of existing plant mix and/or base course) for the standard 200 ft transition and replace with new plant mix. (3) Apply no additional treatment at the bridge end if the roadway within 100 ft of the bridge ends is not showing increased signs of distress compared with the overall project roadway condition.

APPENDIX D SUMMARY OF T-TEST RESULTS

Table D-1 T-test results for crack rating (CR)

Test Pair	Mean	Number of Observations	Hypothesized Mean Difference	t Statistic	P value (two-tail)	t Critical (two-tail)
Approach	9.06	1155	0	-6.444	0.000	1.96
Control	9.46					
Departure	9.06	1155	0	-6.520	0.000	1.96
Control	9.46					
Approach	9.11	1155	0	0.695	0.487	1.96
Approach Slab	9.06					
Departure	9.01	1155	0	-0.590	0.555	1.96
Departure Slab	9.06					
Approach	9.06	1155	0	0.109	0.913	1.96
Departure	9.06					
Approach	7.37	317	0	8.220	0.000	1.96
Control	8.42					
Departure	7.27	317	0	-8.632	0.000	1.96
Control	8.42					
Approach	7.37	317	0	1.701	0.089	1.96
Approach Slab	7.60					
Departure	7.27	317	0	-0.211	0.833	1.96
Departure Slab	7.30					
Approach	7.37	317	0	-0.738	0.461	1.96
Departure	7.27					

Table D-2 T-test results for rut rating (RR)

Test Pair	Mean	Number of Observations	Hypothesized Mean Difference	t Statistic	P value (two-tail)	t Critical (two-tail)
Approach 1	9.27	1013	0	-1.009	0.313	1.96
Approach 2	9.30					
Approach 2	9.30	1013	0	-1.514	0.130	1.96
Approach 3	9.35					
Approach 1	9.27	1013	0	-2.574	0.010	1.96
Approach 3	9.35					
Approach 1	9.27	1013	0	1.525	0.127	1.96
Control	9.22					
Approach 2	9.30	1013	0	2.514	0.012	1.96
Control	9.22					
Approach 3	9.35	1013	0	4.117	0.000	1.96
Control	9.22					
Departure 4	9.37	1013	0	2.141	0.032	1.96
Departure 5	9.31					
Departure 5	9.31	1013	0	1.162	0.245	1.96
Departure 6	9.27					
Departure 4	9.37	1013	0	3.282	0.001	1.96
Departure 6	9.27					
Departure 4	9.37	1013	0	4.814	0.000	1.96
Control	9.22					
Departure 5	9.31	1013	0	2.632	0.009	1.96
Control	9.22					
Departure 6	9.27	1013	0	1.426	0.154	1.96
Control	9.22					

Table D-3 T-test results for IRI

Test Pair	Mean	Number of Observations	Hypothesized Mean Difference	t Statistic	P value (two-tail)	t Critical (two-tail)
Approach 1	76.92	1013	0	-1.892	0.059	1.96
Approach 2	81.02					
Approach 2	81.02	1013	0	-5.654	0.000	1.96
Approach 3	94.25					
Approach 1	76.92	1013	0	-7.502	0.000	1.96
Approach 3	94.25					
Approach 1	76.92	1013	0	7.574	0.000	1.96
Control	63.67					
Approach 2	81.02	1013	0	9.712	0.000	1.96
Control	63.67					
Approach 3	94.25	1013	0	15.652	0.000	1.96
Control	63.67					
Departure 4	112.65	1013	0	6.959	0.000	1.96
Departure 5	95.28					
Departure 5	95.28	1013	0	6.346	0.000	1.96
Departure 6	80.83					
Departure 4	112.65	1013	0	13.497	0.000	1.96
Departure 6	80.83					
Departure 4	112.65	1013	0	24.274	0.000	1.96
Control	63.67					
Departure 5	95.28	1013	0	16.440	0.000	1.96
Control	63.67					
Departure 6	80.83	1013	0	9.866	0.000	1.96
Control	63.67					

APPENDIX E LIST OF BRIDGES WITH SMOOTHNESS AND THICKNESS DATA IN 2014

Bridge ID	IRI_APP (in/mi)	IRI_DEP (in/mi)	IRI_CTR (in/mi)	THK_APP (in)	THK_DEP (in)	THK_CTR (in)	THK_BASE (in)
100495	76.4	119.7	38.5	5.7	3.1	5.3	13
100496	74.0	68.2	46.6	2.3	6.5	4.4	13
130078	136.8	78.9	91.4	13.0	11.9	10.2	9
130079	106.1	106.2	69.7	13.7	13.6	12.1	9
130105	94.5	107.0	69.8	12.2	13.6	11.8	9
130106	116.2	159.1	89.9	12.8	12.3	11.8	9
170083	148.9	81.1	57.5	4.8	7.5	14.2	9
170085	111.0	130.4	44.9	5.1	12.9	5.3	9
170086	121.7	152.7	51.5	11.2	4.4	5.1	9
260054	108.6	108.7	62.7	10.7	5.9	15.3	10
260055	86.7	89.0	62.0	11.6	11.2	15.8	10
260057	96.6	128.8	83.0	12.4	13.9	17.1	10
260060	149.0	98.9	71.0	5.9	8.5	11.7	10
260063	90.8	109.6	63.8	11.7	9.3	14.5	10
260065	67.2	88.6	105.8	6.7	7.1	9.2	10
260067	96.1	124.7	131.4	5.4	7.6	10.4	10
260068	81.3	107.1	72.9	5.9	5.9	13.6	10
260069	86.0	106.7	84.3	6.2	3.5	12.7	10
260070	93.1	88.6	126.1	6.7	7.1	10.7	10
260071	90.3	132.2	62.8	4.8	6.4	13.3	10
260073	96.1	84.2	108.5	5.4	7.6	8.7	10
260078	84.5	141.2	106.6	9.1	7.2	14.1	10
260079	107.7	107.5	74.9	8.7	12.6	15.6	10
260080	93.9	116.1	87.4	14.9	9.1	15.3	10
260081	72.5	83.9	63.5	11.2	10.3	14.2	10
260082	106.8	136.7	77.7	11.5	12.2	15.3	10
290055	111.7	134.7	75.2	10.6	14.3	13.2	10
290061	121.9	103.1	69.7	8.0	12.2	14.4	10
290062	118.9	145.8	92.6	11.7	12.2	13.0	10
290064	213.7	156.0	113.6	8.5	11.6	12.6	10
780017	183.6	84.8	59.8	10.7	9.3	9.2	10
780034	122.7	144.3	65.0	8.8	8.9	9.8	10
780035	93.4	191.9	68.1	4.8	7.6	10.0	10
780036	94.5	125.9	48.8	6.6	6.4	13.0	10
780037	109.0	138.2	93.9	5.7	6.0	8.4	10
780043	93.0	142.4	64.7	9.2	8.9	13.7	10
780044	173.1	103.2	73.2	5.2	5.0	14.6	10
780069	86.6	91.5	59.5	9.6	9.1	9.1	10
780116	137.3	93.5	68.0	6.9	7.2	8.6	10

Bridge ID	IRI_APP (in/mi)	IRI_DEP (in/mi)	IRI_CTR (in/mi)	THK_APP (in)	THK_DEP (in)	THK_CTR (in)	THK_BASE (in)
780117	124.9	117.8	70.6	7.2	9.5	10.0	10
790080	102.0	91.4	79.7	6.5	7.3	8.2	10
790081	100.4	73.2	93.6	8.0	7.8	8.6	10
890115	142.3	119.7	74.8	8.2	8.5	8.5	10
890116	106.3	118.4	84.2	9.2	9.0	9.1	10
890117	106.4	145.8	89.1	9.5	8.6	9.0	10
890118	101.4	111.7	76.2	8.7	8.4	9.1	10
890130	103.9	83.7	61.6	8.8	8.2	9.9	10
930184	60.8	75.8	49.5	5.5	6.2	10.9	10
930187	101.6	70.8	56.8	7.5	8.0	8.1	10
930188	68.2	87.1	52.1	7.3	7.3	8.4	10
930189	99.3	139.8	65.4	7.4	8.2	10.8	10
930198	121.2	92.6	55.1	7.8	8.6	8.7	10
930199	121.3	58.1	58.4	7.5	6.9	8.5	10
930201	127.4	120.8	60.7	7.2	2.7	10.5	10
930251	96.1	104.3	60.2	8.7	7.4	10.1	10
930371	38.4	149.2	84.4	4.8	8.5	8.0	10
930386	146.4	52.1	52.8	10.5	5.5	9.8	10
930387	54.4	93.0	46.1	10.1	10.9	10.6	10
930445	76.8	104.7	60.5	7.2	12.5	13.7	10
930499	80.3	90.1	37.8	6.7	4.0	7.5	10
930500	94.8	43.3	72.0	6.8	6.8	7.0	10
940111	52.5	147.1	54.5	9.9	9.4	10.0	10
940112	81.9	93.0	49.3	11.4	10.8	10.0	10
940115	84.9	96.9	54.8	10.4	12.0	10.8	10
940116	79.3	95.1	53.2	10.9	12.0	10.2	10
940122	92.1	97.0	59.2	11.9	12.4	10.1	10
940126	82.6	77.9	56.7	11.6	11.1	10.1	10
940127	97.3	52.6	46.8	13.2	11.1	10.6	10
890131	78.3	116.7	58.9	8.9	8.9	9.4	10
930261	73.5	212.4	143.0	6.2	6.2	6.5	10
930262	101.9	132.0	88.2	7.2	7.2	7.6	10
930273	102.8	116.6	64.2	6.0	6.0	7.3	10
930458	101.9	170.8	89.0	8.2	6.5	7.5	10

Note: IRI_APP, IRI_DEP, and IRI_CTR are average IRI over bridge approach pavement section, bridge departure pavement section, and control section, respectively. THK_APP, THK_DEP, and THK_CTR are average pavement surface layer thickness of bridge approach pavement section, bridge departure pavement section, and control section, respectively. THK_BASE is the base layer thickness of the roadway pavement.

APPENDIX F POOR/VERY POOR BRIDGE APPROACH/DEPARTURE ASPHALT PAVEMENTS

Table F-1 List of 21 bridges with poor or very poor approach asphalt pavements

District ID	County ID	Roadway ID	Roadway Side	Bridge ID	US Route	Average Rut Depth (in)	IRI (in/mi)
1	13	13075000	L	130108	I-75	0.04	262
1	13	13075000	L	130105	I-75	0.03	239
2	72	72001000	L	720370	I-295	0.56	102
2	72	72001000	L	720412	I-295	0.12	229
2	72	72002000	L	720564	I-295	0.08	282
2	26	26260000	R	260071	I-75	0.02	228
2	29	29180000	R	290064	I-75	0.42	257
2	72	72002000	R	720565	I-295	0.06	252
3	61	61001000	L	610070	I-10	0.60	137
3	61	61001000	R	610071	I-10	0.51	171
3	48	48260000	L	480062	I-10	0.15	247
3	50	50001000	R	500096	I-10	0.14	238
3	50	50001000	R	500054	I-10	0.22	226
3	54	54001000	R	540951	I-10	0.31	261
5	18	18130000	L	180070	I-75	0.03	236
5	36	36210000	L	360065	I-75	0.31	239
5	77	77160000	L	770086	I-4	0.05	303
5	36	36210000	R	360024	I-75	0.37	273
5	36	36210000	R	360038	I-75	0.12	299
5	75	75280000	R	750203	I-4	0.22	255
6	87	87200000	L	870140	I-395	0.02	275

Table F-2 List of 34 bridges with poor or very poor departure asphalt pavements

District ID	County ID	Roadway ID	Roadway Side	Bridge ID	US Route	Average Rut Depth (in)	IRI (in/mi)
1	13	13075000	R	130079	I-75	0.51	103
1	01	01075000	R	010079	I-75	0.03	292
1	03	03175000	R	030273	I-75	0.01	223
1	03	03175000	R	030241	I-75	0.04	299
1	03	03175000	R	030233	I-75	0.04	299
1	03	03175000	R	030258	I-75	0.09	233
1	03	03175000	R	030255	I-75	0.00	244
1	03	03175000	R	030268	I-75	0.03	273
1	03	03175000	R	030229	I-75	0.04	331
1	03	03175000	R	030190	I-75	0.06	238
1	03	03175000	R	030243	I-75	0.03	260
1	03	03175000	R	030245	I-75	0.04	260
1	03	03175000	R	030272	I-75	0.01	250
1	03	03175000	R	030252	I-75	0.06	235
1	03	03175000	L	030027	I-75	0.08	226
1	03	03175000	L	030012	I-75	0.10	247
1	03	03175000	L	030234	I-75	0.02	226
1	12	12075000	L	120100	I-75	0.09	249
2	72	72001000	R	720386	I-295	0.54	139
2	72	72001000	L	720389	I-295	0.50	67
2	29	29180000	R	290064	I-75	0.25	248
2	26	26260000	L	260069	I-75	0.00	222
2	27	27090000	L	270047	I-10	0.20	286
2	72	72002000	L	720126	I-295	0.07	324
3	48	48260000	R	480070	I-10	0.06	331
3	58	58002000	L	580167	I-10	0.05	228
4	93	93220000	R	930201	I-95	0.09	224
4	86	86070000	L	860128	I-95	0.14	259
5	70	70220000	R	700123	I-95	0.03	235
5	75	75280000	R	750203	I-4	0.01	269
5	77	77160000	R	770087	I-4	0.12	325
5	79	79002000	L	790064	I-95	0.03	233
5	79	79002000	L	790077	I-95	0.27	326
6	87	87200000	R	870265	I-395	0.03	222

APPENDIX G RESPONSES FROM FDOT DISTRICTS ON AVERAGE COST INFORMATION ASSOCIATED WITH PAVEMENT REHABILITATION

1. What are the average contract lump sum prices for the item of mobilization (i.e., preparatory work and operations in mobilizing for beginning work) in bridge approach pavement milling/resurfacing and reconstruction project, respectively? (If data for bridge approach pavements are not available, please provide those for regular highway pavements.)

Responses:

- **District 1:** Typically we estimate 10% to 20% of the total project cost for mobilization. This number could change based on different factors, but this is what we typically budget.
- **District 2:** This would vary depending on the overall scope of the project, but would generally fall within the range of 3.5% to 7% for resurfacing projects, with lower numbers more likely and the higher numbers on projects with significant amounts of non-paving work, such as drainage, sidewalk, signals, etc. The most likely number on a straight resurfacing project would be 3.5% to 4%.
- **District 6:** Typically, this is estimated at 8.5% - 10% of the total project cost.

2. What is the average contract lump sum for temporary traffic control (TTC) in bridge approach pavement rehabilitation areas? What are the average number of TTC days for bridge approach pavement milling/resurfacing and reconstruction project, respectively? (If data for bridge approach pavement areas are not available, please provide those for regular highway pavement area.)

Responses:

- **District 1:** Typically we estimate 10% to 25% of the total project cost for MOT depending on several factors. I can't give you an average number of days for MOT. That would vary depending on how long construction would take.
- **District 2:** Overall, probably about $550 per day. This could be as much as double in a congested urban area with heavy traffic.
- **District 6:** Typically, this is estimated at 10% of the total project cost.

3. What is the average cost of milling existing asphalt pavement at a certain depth (e.g., 1 in, 1 ½ in, 2 in, 2 ¾ in, 3 in, 4 in, 5 in, 6 in, and 7 in, etc.) per square yard (SY) in your district (for example, $2.77 per SY at 1 in depth)?

Responses:

- **District 1:** See the following link. You can find a list of pay items averages based on different timeframes and different locations (statewide or other). http://www.fdot.gov/programmanagement/Estimates/HistoricalCostInformation/HistoricalCost.shtm
- **District 2:** For FDOT District 2, over the past year (8/1/16 to 8/1/17), the averages per SY are as follows: 1 in ($1.98); 1.5 in ($1.92); 2 in ($1.64); 2.75 in ($1.72); 3 in ($2.33);

4 in ($2.76); and 5 in ($5.52). In addition, if you use a depth not used on the rest of the project in a small quantity you can expect significantly higher prices, perhaps double these numbers

- **District 6:** $2 – 7$. FDOT's historic cost information can be found at the following site. This site has average unit prices on FDOT projects from the last year for 14 areas of the state. Attached are the latest reports for District 6 (Miami-Dade and Monroe Counties). These reports are updated monthly and may not include costs for all pay items if it has not been used on a recent project. The site also has historic statewide averages. http://www.fdot.gov/programmanagement/Estimates/HistoricalCostInformation/HistoricalCost.shtm; To understand FDOT's estimating process and pay item numbering system, you should be familiar with the Basis of Estimates (BOE), the manual and list of pay items can be found at these links: http://www.fdot.gov/programmanagement/Estimates/BasisofEstimates/BOEManual/BOEOnline.shtm; https://fdotewp1.dot.state.fl.us/designquantitiesandestimates/#/boe; For estimating purposes, FDOT does not distinguish between the pavement design in the "transition area" outside the approach slabs from the regular pavement, so the same pay items would apply.

4. What is the average cost of overlay for a certain asphalt mixture type (e.g., SP-9.5, SP-12.5, SP-19, FC-5, FC-9.5, and FC-12.5, etc.) per ton (T) in your district?

Responses:

- **District 1:** See the following link. You can find a list of pay items averages based on different timeframes and different locations (statewide or other). http://www.fdot.gov/programmanagement/Estimates/HistoricalCostInformation/HistoricalCost.shtm
- **District 5:** I have a site I can access that can get you historical costs by pay item from the Specifications Office. http://www.fdot.gov/programmanagement/Estimates/HistoricalCostInformation/HistoricalCost.shtm
- **District 6:** See pay item series 334-1-xx for structural course, 337-7-xx for friction course. For pavement reconstruction, additional costs would also be required: see pay items 110-1-1 (clearing and grubbing), 120-x (excavation or embankment), 160-4 (stabilization), and 285-x (base course). Also note, pavement reconstruction may also impact other existing roadside features, like curbing (520-x), side walk (522-x), guardrail (536-x), and sobbing (570-x). Also for either resurfacing or reconstruction, new pavement markings would be required.

5. Could you provide some previous cost-estimation contracts/reports (including overlay or reconstruction design, treatment area, cost-estimation lists, etc.) about milling & resurfacing or reconstruction of bridge approach pavement in your district (If files for bridge approach pavements are not available, please provide those for regular highway pavements.)?

Responses:

- **District 1:** I would suggest you view our construction website, where you can view bid tabs for previous project that were "let". See the link below. You can find recent projects

that were bid along with their bid tabs.
http://www.fdot.gov/contracts/Lettings/Letting_Project_Info.shtm

- **District 2:** T2639 is replacement of the CR356C bridge over the Fenholloway River and includes reconstruction of the approaches. That is about all I have that matches this criteria in the past year. I could provide info on generic milling and resurfacing projects if needed.