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Analysis of Distresses in Asphalt Pavement Transitions on Bridge Approaches and Departures

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Analysis of Distresses in Asphalt Pavement Transitions on
Bridge Approaches and Departures

by

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A thesis submitted in partial fulfillment
of the requirements for degree of
Master of Science in Civil Engineering
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College of Engineering
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DEDICATION

I dedicate this thesis to my family especially my parents Mr. Ganga Prathap Rajalingola and Mrs. Anuradha Rajalingola. Because of their hard work, I was able to study in abroad. My major professor, Dr. Qing Lu, taught me how to think critically, how to understand and explore research topics clearly in my entire graduate study period. I really feel that without their inspiration, guidance, and dedication, I would not be able to go through the strenuous process to complete my thesis.

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ABSTRACT

Some highway agencies in the United States are experiencing frequent distresses in asphalt pavements on bridge approaches/departures. Commonly observed distresses include alligator cracking and rutting, which reduce roadway smoothness and safety. To lessen the distresses in pavements it is needed to investigate the extent and root causes of the problem. Based on Florida highway conditions, this research study mainly focused on: 1. Literature review and identification of the extent of the problem; 2. Collection of relevant pavement condition data and descriptive analysis; 3. Development of statistical models to determine factors influencing the distresses in asphalt pavements on bridge approaches/departures. To the best of my knowledge, this is the first study that uses a statistical model to determine the factors that are responsible in causing asphalt pavement distresses on bridge approaches/departures.

As part of the literature review a nationwide questionnaire survey was targeted towards U.S state DOTs. The data collection and analysis specific to the Florida highways found that in 2015 on Florida Interstate highways, about 27% bridges with asphalt pavements on their approaches/departures showed signs of cracking, and about 20% bridges have noticeable rutting in their approach or departure pavements.

A random parameter linear regression model was applied to examine the factors that may influence distresses in asphalt pavements in Florida. Pavement condition was evaluated based on the Florida Department of Transportation (FDOT) 2015 pavement condition data and video log images, and other relevant data were collected from various sources such as FDOT Roadway

Characteristics Inventory (RCI) database, FDOT pavement management reports, and FDOT Ground Penetrating Radar (GPR) survey reports. A constraint existed in the availability of the GPR data that can give pavement layer thickness, which limited the number of bridge approach pavement sections included in the statistical modeling. Based on the limited data, the estimated results from the random parameter linear regression model showed that the variables influencing distresses in asphalt pavements on bridge approaches/departures, in terms of rutting and roughness, may include pavement age, annual average daily truck traffic, and surface friction course.

CHAPTER 1: INTRODUCTION

This study deals with the frequent distresses in asphalt pavements on the Interstate Highway System where bridge approaches/departures transition to regular roadways. This study mainly focuses on bridge approach and departure sections, which are present next to the approach slab on either side (note: the approach slab on the departure side is also named as a departure slab). Figure 1 shows the sections on the pavement on which the study has been conducted. Distresses were observed at higher frequency at these locations.

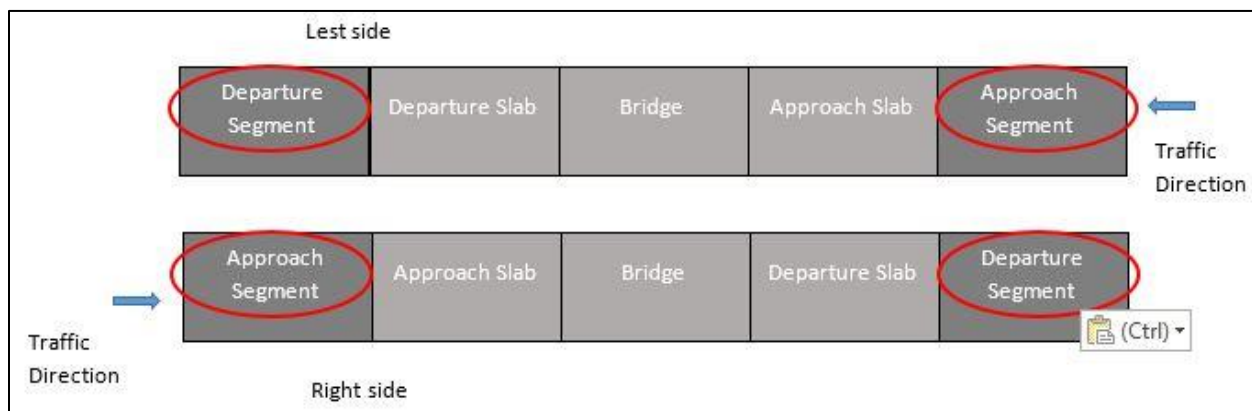


Figure 1 Schematic Diagram of Bridge Approach/Departure Slab and Pavement Sections

Distresses such as rutting and alligator cracking that lead to poor ride quality, reduced safety, and more maintenance cost have been found along bridge approach/departure sections (Hall et al., 2001). Among many other factors, the increase of these problems arises mostly in the outer travel lane and this phenomenon is usually attributed to predominance of truck traffic in those lanes. Additionally, one other potential cause of pavement distresses on bridge approach and departure sections is a poor pavement mix/type. When an incompatible or poorly designed pavement mix is utilized for construction it might lead to infiltration of water into the pavement

which will subsequently cause cracks to form inside the pavement structure (Christopher et al., 2006). Such cracks will then lead to pumping of pavement as traffic moves over the pavement. One other likely cause of distresses on the bridge approach/departure pavement is insufficient thickness of the asphalt pavement layer. Such deficiencies in thickness will also lead to premature pavement failure.

A nationwide survey was conducted towards various transportation departments/agencies regarding this topic in 2016. The results of this survey revealed that most of the state DOTs have dealt with pavement distress issues at asphalt pavement locations adjacent to the approach slab.

Many survey participants opined that distresses are caused by poor compaction, which leads to a weak base, insufficient drainage, and settlement issues. In states with cold climate where snowing is common, pavement damages due to plows and studded tires are also reported. It was also reported that, generally, cracking on these sections occurs due to inadequate drainage behind the abutments and inadequate usage of non-erodible bases.

Few other survey participants reported that, according to them, pavement distresses occur due to improperly placed asphalt mixtures as well as poorly maintained joint seals. Joint seals in bad condition inhibit proper expansion and contraction of joints at pavement/bridge interface, leading to distresses such as grade settlement or pavement expansion. Another popular opinion expressed by survey respondents is that, distresses also appear due to saturated or weak subgrade, moisture infiltration into pavement (stripping), and differential loading responses between asphalt section and bridge ends.

This survey also focused on identifying structural deficiencies prevalent at study locations. Accordingly, some questions included in the survey aimed to obtain relevant information from respondents. Some survey participants reported that, occasionally, the bridge approaches have

been evaluated as structurally deficient because of drastic temperature changes, and variations in subgrade soil. Also, difficulty in achieving optimal compaction at problematic locations resulted in poor pavement quality. In some cases, poor contractor workmanship, heavy traffic, inadequate compaction efforts of the base near the bridge ends, and bumping of the pavement from the movement of the approach/departure slabs over time may also be the causes. Few other survey participants opined that insufficient compaction at the abutment gives raise to pavement damage at bridge ends. In some states, it was also observed that thin asphalt structure and compression failure of underlying concrete tend to result in damages in asphalt pavements on bridge approaches/departures. More discussion of this survey is continued in further chapters.

In addition to investigating the causes of frequent damages in asphalt pavements on bridge approaches and departures, an attempt was made to provide suggestions on how to improve smoothness and ride quality at the study locations. For this study, data has been collected from mainly three sources: FDOT video log image data which can found from FDOT website; pavement characteristics data collected directly from FDOT materials office; and other relevant data, such as bridge number, speed limit, number of lanes, widths of lanes, cross slope, predominant subgrade soil type, base layer type, base layer thickness, annual average daily traffic (AADT), and annual average daily truck traffic (AADTT), can be acquired from the FDOT Roadway Characteristics Inventory (RCI) database (FDOT, 2016). Traffic input over design periods expressed in terms of an equivalent number of 18-kip single-axle loads (ESAL) can be achieved from FDOT Transportation Data and Analytics Office.

Therefore, to lessen distresses at the study locations specific research objectives are as follows:

- Identifying the main causes of premature and excessive damages in asphalt

pavements on bridge approaches/departures,

- Developing performance models for asphalt pavements on bridge approaches/departures based on field data.

A literature review of past research conducted on pavement distresses on bridge approach/departures is necessary to understand how different studies have tackled this issue and to give a focus to the present study. In the next section, an investigation of previous studies on this topic is presented.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

As mentioned earlier, this study focuses on identifying factors associated with asphalt pavement distresses on bridge approaches and departures. To gain a deeper understanding of this problem, it is necessary to investigate the previous studies that dealt with the same problem. Unfortunately, there were not many studies that focused on the specific problem being discussed here. This section summarizes the literature review conducted as a part of this study. Additionally, a summary of a nationwide questionnaire survey is also included in this section.

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. A study by the Oregon Department of Transportation (ODOT) in 2011 opined that pavement sections on bridge approaches rapidly deteriorate for various reasons (ODOT, 2011). The problems with bridge approach 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 maintenance frequency and expenditure, and increase user cost such as delay due to traffic interruption by maintenance work and added vehicle damage (Phares et al., 2011; Long et al., 1998).

This literature review was performed to gather information related to asphalt pavements on bridge approaches and departures, including pavement structures and materials used, common

types of pavement distresses, major factors contributing to pavement distresses. While the objectives of this study 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. The typical elements of a bridge approach system are shown in the Figure 2 (Bernadette, et al., 2002).

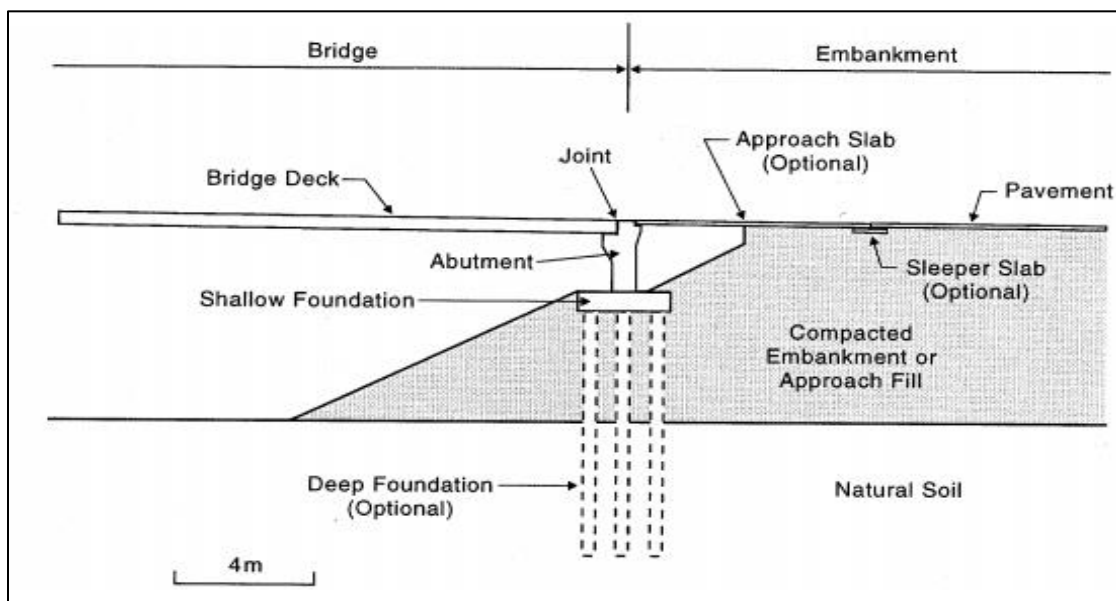


Figure 2 Elements of Typical Bridge Approach System (Bernadette et al., 2002)

2.2 Common Types and Primary Causes of Asphalt Pavement Distresses on Bridge Approaches and Departures

There are various types of distresses that are common in asphalt pavements on bridge approaches/departures and in regular pavements, such as cracking, rutting, and bleeding. The common causes of distresses on bridge approach pavement are given in Table 1. The performance

of a bridge approach is affected by the design and construction of the bridge deck, abutment, and foundation as well as the roadway pavement system, embankment, and embankment foundation. Major problems usually are attributed to excessive compression of the embankment and foundation soils or inadequate compaction of the approach embankment or both. Localized soil erosion, usually associated with inadequate provisions for drainage, also may be a contributing factor. Frost heave or swelling soils can also be problems in some areas (Wahls, 1990).

Depending on the gradation of the fill and foundation soils, erosion can occur beneath the approach roadway, lowering the elevation of the approach when the drainage system is poor. The severity of elevation difference between the bridge approach and deck may cause various levels of damage to vehicles. Settlements may occur due to simple factors in design deficiency or the fact that the approach pavement is not constructed according to the design specifications. Poor drainage leads to fill washouts and develops voids under the approach pavements. Distresses may also occur due to heavy trucks that move from bridge deck onto the approach which is a sudden change from a rigid to a flexible surface (Wahls, 1990).

Distresses may be aggravated if there is a reduced thickness of approach asphalt pavement when compared to the regular asphalt pavement. The bridge approach settlements appear due to lack of sufficient compaction of the backfill materials and also difference in elevations of approach pavements and the bridge deck caused by unequal settlement of embankments and abutments. Poor performance of the approach/departure pavements is affected by mix design, environmental factors, quality of materials, and construction (Wahls, 1990).

A recent study indicated that settlement on bridge approach pavements may be accelerated due to consolidation of the backfill materials, consolidation of foundation soils, and poor drainage (Helway et al., 2007). The same study also revealed that settlements on bridges cause rider

discomfort, failure of bridge structure, increase of long term maintenance cost and ultimately lead to poor driving conditions. Also, they discussed some techniques to repair the bump by slab jacking, overlays or asphalt patching and replacement of an approach slab. They also performed two effective mitigations techniques (geosynthetic-reinforced fill and flowable fill) to lessen settlements on approaches for two different foundation conditions: incompressible and compressible.

A study conducted by Laguros et al. (1990) states that factors including expansion, age of the approach slab and the height of embankment negatively impact the backfill performance. Similarly, it was also revealed that poor drainage leads to soil erosion which might result in skewness of the bridge. The same study also observed that flexible pavements are more susceptible to more settlements than rigid pavements during initial stage of construction (short term performance), while both pavement types performed similarly over the long term.

2.3 Nationwide Questionnaire Survey

In this study, a national level questionnaire survey was conducted to identify the asphalt pavement transitions on bridge approaches and departures. The survey was targeted towards state DOTs in the U.S. with the aim of collecting information on a variety of aspects related to bridge approach/departure pavements in their respective states. The survey received responses from 33 states, among which over 60% respondents noticed more distresses in asphalt pavements adjacent to bridge approach/departure slabs than on regular roadways. In about 30% of the 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 longitudinal grade. Many states attributed the excessive distresses in bridge approach pavements to inadequate compaction, insufficient drainage, and differential settlement. Over 30%

states perform maintenance and rehabilitation activities more frequently on bridge approach pavements, and many states do not have special maintenance and rehabilitation strategies and guidelines for bridge approach pavements.

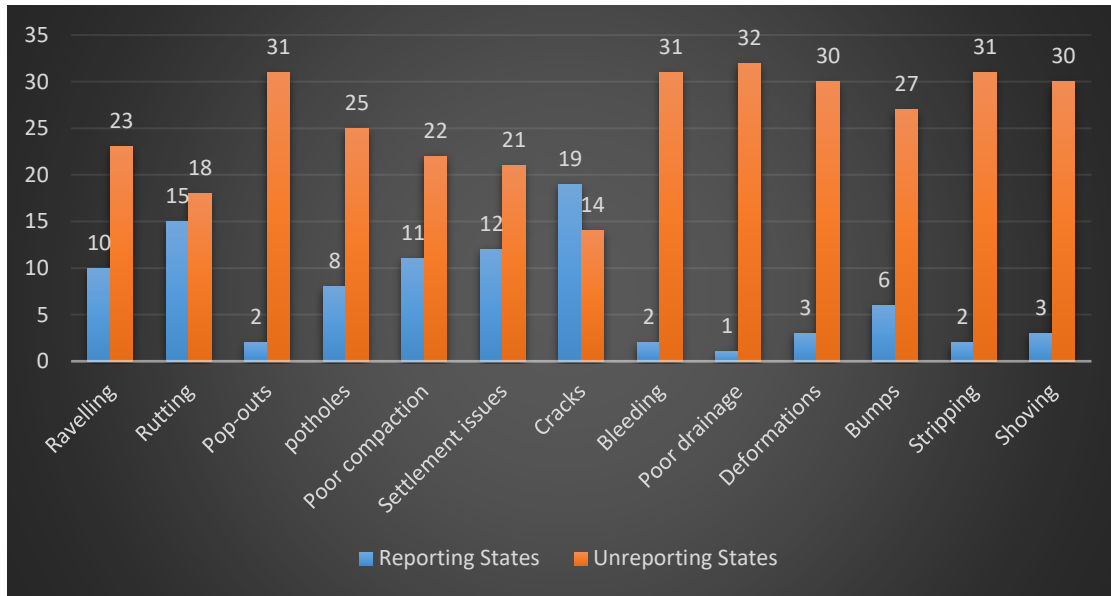


Figure 3 Frequencies of Reported Distresses

The results shown in Figure 3 are obtained from the nationwide questionnaire survey. As can be seen from the figure, 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.

In addition to collecting information on the types of pavement distresses on bridge approaches and departures, this survey also attempted to identify what professionals from state DOTs across the U.S. think are the most important factors that cause the distresses. The causes of pavement distresses at problematic locations as reported by the respondents are summarized below.

Engineers from Arizona DOT reported that the distresses in asphalt pavement transitions are due to material change from rigid to flexible. Several other DOTs reported that damages on bridge approaches and departures arose due to insufficient compaction that eventually led to a

weak base. Inadequate drainage and settlement issues are also reported by many states. Alaska DOT opined that damages near problematic bridges are due to plows and studded tires, which are commonly used in their jurisdiction. Caltrans answered that most of the cracks appear due to inadequate drainage behind the abutments and insufficient usage of non-erodible base.

Similarly, Georgia and Hawaii DOTs reported that they have observed the main causes for pavement distress as improperly placed asphalt mixtures as well as 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.

Oregon DOT reported the potential causes of pavement distresses on 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. In South Carolina, the DOT reported that temperature changes at problematic locations and variation in subgrade result in segregation. Also, difficulty in achieving optimal compaction at problematic locations also results in poor pavement quality.

Poor contractor workmanship was cited as a reason for distresses by MnDOT. In Rhode Island the DOT engineers identified the potential causes of asphalt pavement damage as 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 rise to pavement damage at bridge ends. NDOT said that the cracks on bridge approaches and departures appear due to saturated subgrade. MODOT and UDOT mentioned differential settlement between the pavement and bridge structures to be the

cause of distresses on bridge approaches and departures. In Washington and Wisconsin states, the distresses are caused by thin asphalt structure and compression failure of underlying concrete.

The observations made by experienced pavement engineers from various state DOTs provide valuable insight on what kind of factors might affect pavements on bridge approaches and departures. The results of this survey along with a strong statistical analysis of pavement data collected in Florida will help in achieving the prime objective of this study.

2.4 Previous Investigation Suggestions on Mitigation of Pavement Distresses

A study conducted by FHWA (James, et al., 1991) revealed that 70 percent of the bumps at approach slabs can be reduced by better feathering. Removal of the discontinuity to a significant level can be done by milling of existing asphalt pavements before the approach slabs for some distance. However, it is not known whether a standard exists for such treatment. Pavement design engineers should provide a desired profile to the maintenance personnel if there is no such specific standard. During the field inspections discontinuities were observed at most of the instances, which justified development of a better asphalt concrete overlay near approach slabs. The primary function of the approach slab is to provide a gradual transition, or a ramp, between the fixed superstructure and the settling embankment. Without an approach slab, the “bump” at the end of the bridge becomes much more abrupt. However, to maintain the level of rider comfort at approaches, Briaud et al. (1997) recommended a maximum allowable change in slope of 1/200, based on studies by Wahls (1990) and Start et al.(1995). Long et al.(1998) also proposed a relative gradient of less than 1/200 to ensure rider comfort and a gradient of between 1/100 and 1/125 as a criterion for initiating remedial measures.

Moreover, Ohio State DOT stated that it is important to keep the approaches to the bridge as smooth as possible. While new alignments (roads) will have some area where embankment will

not settle somewhat even after an optimum compaction, the pavement end of the approach slab may still settle by creating uneven transitions onto the bridge from trucks.

The results of nationwide survey made it clear that there exist multiple contributing factors to asphalt pavement distresses at bridge approaches and departures. These results would be helpful in identifying what factors are responsible for the same problem in Florida. The next step in this study is to analyze data collected from Florida DOT, results of the nationwide survey will aid in interpretation of the results of data analysis task and consequently in identifying factors causing asphalt distresses at bridge approaches and departures in Florida.

Table 1 Common Types and Potential Causes of Asphalt Pavement Distresses on Bridge Approaches/Departures

Distress	Description	Possible Causes
Approach slab ramp	Differential settlement between bridge and approach slab	<ul style="list-style-type: none"> • Consolidation of foundation soil • Embankment vertical deformation • Poor compaction of filler
Dip after approach slab	Differential settlement between approach slab and pavement	<ul style="list-style-type: none"> • Consolidation of foundation soil • Embankment vertical deformation • Poor compaction of filler
Differential settlement at pavement-bridge interface	Differential settlement at pavement-bridge interface	<ul style="list-style-type: none"> • Consolidation of foundation soil • Embankment vertical deformation • Poor compaction of filler

Table 1 Continued

Distress	Description	Possible Causes
Alligator (fatigue) cracking	Interconnected or interlaced cracks in the wheel path, forming a series of small polygons.	<ul style="list-style-type: none"> • Excessive loading • Weak surface, base, or subgrade • Thin surface or base layers • Poor drainage
Longitudinal cracking in wheel paths	Longitudinal cracks are predominantly parallel to pavement centerline.	<ul style="list-style-type: none"> • Aging effect of asphalt • Excessive loading • Impact factor • Weak surface, base • Thin surface or base • Poor drainage • Poorly constructed paving joint • Shrinkage of asphalt layer • Daily temperature changes • Cracks present in sub layers reflect on to the surface layer.
Transverse and map cracking	Transverse cracks are predominantly perpendicular to the pavement centerline.	<ul style="list-style-type: none"> • Aging effect of asphalt • Voids exist beneath the slab • Embankment compression
Cracking at the expansion joint	Tensile-extrusion failure	<ul style="list-style-type: none"> • Expansion-contraction cycle • Impact load effect • Expansion joints failure
Cracking at the transition from approach slab to pavement	Reflective cracking at joints	<ul style="list-style-type: none"> • Poor compaction • Impact load effect • Reflection cracks • Settlement

Table 1 Continued

Distress	Description	Possible causes
Rutting (mix rutting or subgrade rutting)	Surface depression in the wheel paths	<ul style="list-style-type: none"> • Poor compaction • Excessive loading • Weak asphalt mixtures • Insufficient design thickness • Moisture infiltration
Shoving	Longitudinal displacement of a localized area of the pavement	<ul style="list-style-type: none"> • 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.	<ul style="list-style-type: none"> • Mixture problems • Improper construction practices and high temperatures.
Bleeding or flushing	A film of asphalt binder on the pavement surface.	<ul style="list-style-type: none"> • Mixture problems • Improper construction practices and high temperatures.
Raveling	Loss of bond between aggregate particles and the asphalt binder	<ul style="list-style-type: none"> • Aggregate segregation • Inadequate compaction • Poor mixture quality • Asphalt hardening • Insufficient thickness • Excess moisture in the pavement layers weakens the pavement structure. • Consolidation or lateral movement of any pavement layers under traffic.

Table 1 Continued

Potholes	Depressions in the pavement surface that penetrate all the way through the HMA layer down to the base layer	<ul style="list-style-type: none">• Thin surface layer• Moisture infiltration• Excessive loading• Poor surface mixtures• Weak spots in the base or subgrade• Continued deterioration of another type of distress.
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Sources: (Lenke, 2006; MDOT, 2002; White et al., 2005; Asphalt Institute, 2009; MDOT, 2016; Phares et al., 2011; Scullion, 2001)

CHAPTER 3: DATA COLLECTION AND DESCRIPTIVE ANALYSIS

3.1 Introduction

Pavement condition data pertinent to Florida highways were acquired and analyzed in order to identify the extent and causes of asphalt pavement damages on bridge approaches and departures present in Florida. In this chapter, the focus is on analyzing pavement condition data with the purpose of identifying the extent of pavement distresses on bridge approaches/departures. Additionally, an analysis of asphalt layer thickness was also done.

The sources for the data utilized in this study include FDOT highway video log images available at FDOT website and 2015 pavement condition data provided directly by the FDOT State Materials Office.

In total, 1155 bridges were identified on Florida interstate highways which have asphalt pavements on bridge approaches/departures.

3.2 Pavement Condition Analysis Based on Video Log Data

FDOT maintains a searchable database consisting of roadway images that come under FDOT's jurisdiction. This database is managed by the FDOT's video log program. The roadway images can be searched and viewed based on the ID and mile posts of each roadway section.

Images collected by the FDOT 2016 video log program were utilized to evaluate the conditions of asphalt pavements adjacent to the 1155 bridges of interest. The evaluation was done in compliance to the FDOT 2015 Flexible Pavement Condition Survey Handbook (FDOT, 2015). Main steps in the evaluation process are discussed in the following paragraphs.

The beginning point of a bridge, as depicted in Figure 4, were identified initially based on the beginning mile post of the bridge. From the beginning point of a bridge, a rectangular segment is surveyed backwards (i.e., against traffic direction). The first segment is the approach slab, and the other segment is of approximately 26 feet long and 12 feet in wide. Similarly, a segment on the other side of the bridge was analyzed, including the departure slab and one 26-ft segment. A 26 feet long segment can conveniently be identified using the video log images. Any image by clicking the video images “Frame Forward” button moves to a 0.05 mile, which is 26.4 feet. Similarly, each click on the ‘Frame Backward’ button makes a 26.4 feet movement of the image.

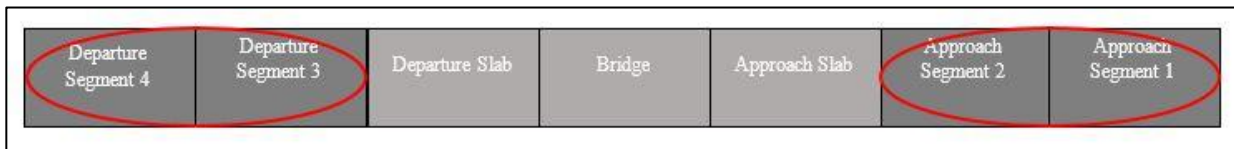


Figure 4 Schematic Depiction of Survey Area in One Lane around a Bridge

The 12 feet width segments before and after the slabs are virtually divided into five longitudinal sections, as depicted in Figure 5. As a result, each survey segment has two sub-segments: wheel path area and outside wheel path area.

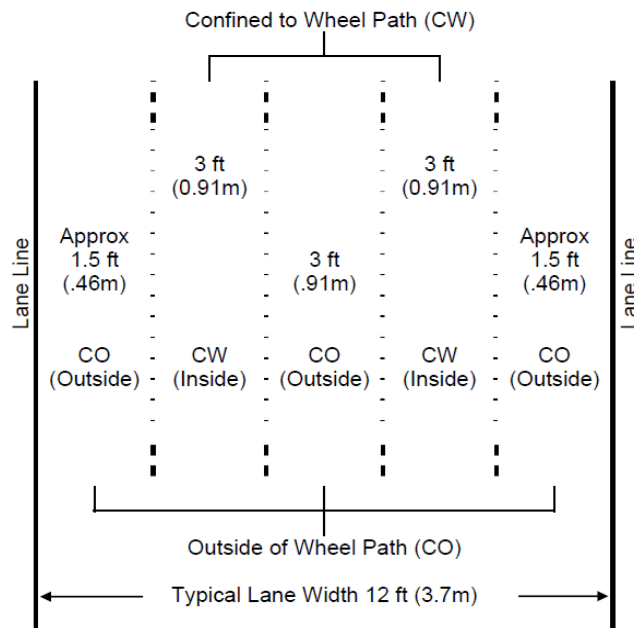


Figure 5 Wheel Path Designation in a Lane (FDOT, 2015)

Each rectangular segment was visually recorded, for five different types of pavement distresses 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 $\frac{1}{8}$ inch (3.18 mm) wide in either the longitudinal or the transverse direction. These may have slight spalling and slight to moderate branching.

- II Cracking: Cracks greater than $\frac{1}{8}$ inch (3.18 mm) and less than or equal to $\frac{1}{4}$ inch (6.35 mm) 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 $\frac{1}{4}$ inch (6.35 mm) wide that have formed cells less than 2 feet (0.61 m) on the longest side, also known as alligator cracking.

- III Cracking: Cracks greater than $\frac{1}{4}$ inch (6.35 mm) 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 a portion 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 FDOT 2015 Flexible Pavement Condition Survey Handbook (FDOT, 2015).

A lane section of 26-ft length located far away from the bridge (usually 0.3 - 0.5 miles away from the bridge) was chosen as the control section. Pavement distresses on this section were assessed visually and recorded in the same manner as explained previously.

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 two approach segments is used to represent the CR of the bridge approach pavement, while the average CR value of two departure segments represents the CR of the bridge departure pavement.

One limitation of the video log data is that, it is not possible to identify or estimate the rutting damage incurred by the pavement using the images/videos. Another constraint is that patching, and raveling could not be separately recorded for within and outside wheel paths due to the difficulty in identifying the wheel-path/outside-wheel-path areas precisely from images. To overcome this, these defects 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 are for only the outer lane of a highway. In few cases, the log is for the lane next to the outer lane. These two cases were not distinguished in the visual assessment. Instead, it is assumed that all the video logs are from the pavement design (truck) lane.

3.2.1 Analysis Results of Pavement Distresses Based on Video Log Images

The crack rating (CR) computed in the visual assessment reflects the degree of distress in asphalt pavements on bridge approaches and departures. CR was used as the pavement condition indicator for analyzing the extent of distresses. The analysis was performed for the entire state of Florida. It was observed that nearly one third of bridge approaches and departures exhibited more pavement distresses than regular roadway sections.

3.2.2 Overall Analysis and Results

Figure 6 portrays a summary of the CR for asphalt pavements at five distinct locations. Clearly, overall the CR is similar for bridge approach pavements and departure pavements, with an average value of 9.1. This value is lower than the average CR value of 9.5 from control sections

(i.e., regular roadway pavements). This fact shows that, the overall condition of bridge approach/departure pavements is worse than that of regular roadway pavements. It should be noted that the approach and departure pavement conditions have a little variation than those of control sections.

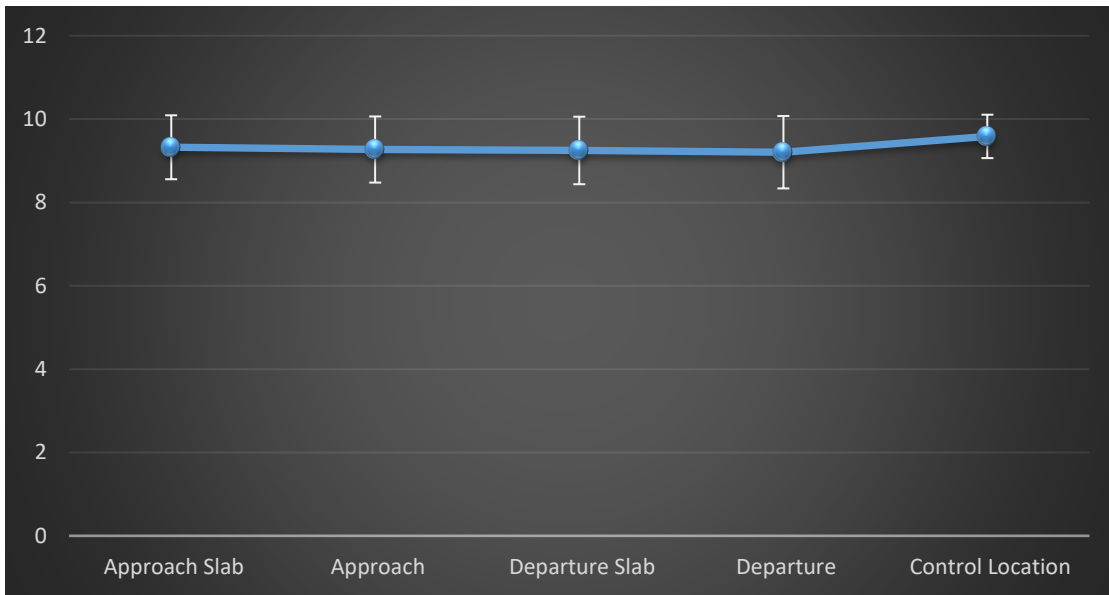


Figure 6 Summary of Crack Rating (CR) of Asphalt Pavements on all Bridges

This study found that, 317 of the 1155 bridges evaluated have a CR value of 9 or less for both approach and departure pavements. These approach and departure pavements showed a general trend of lower CR compared to control sections. On an average, the CR is around 9.2 for bridge approach or departure pavements, while it is 9.6 for control sections, as shown in Figure 6.

The overall CR difference between approach/departure pavements and control sections goes up compared to the all-bridge scenario presented in Figure 7. More importantly, the average control section CR drops from 9.6-inch Figure 6 to 9.5-inch Figure 7. This indicates that the condition of approach/departure pavements deteriorated faster than that of control section (regular roadway) pavements.

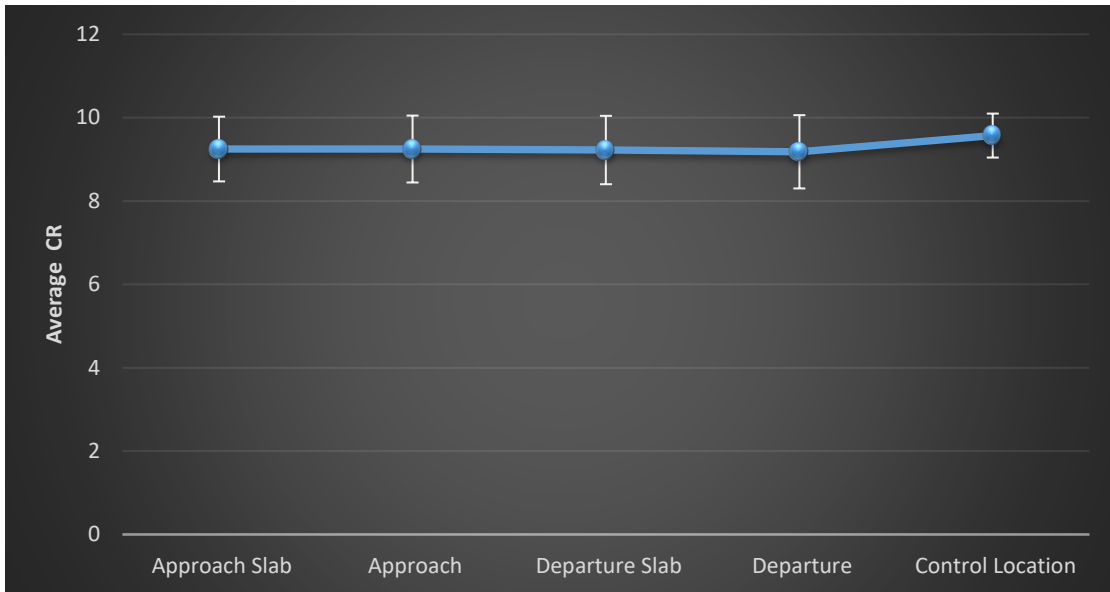


Figure 7 Summary of Crack Rating (CR) of Asphalt Pavements on Bridges Showing Pavement Distresses

Figure 7 illustrates the distribution of CR at approach, departure, and control sections. It can be noted that the pavement is in a good condition overall. At approaches and departures, nearly 85 percent segments exhibited CR values within a range of 8-10. At control sections, this group rises to over 90 percent which is even better. Figure 7 also reveals that nearly 15 percent of approach and departure pavements have a CR value below 8.

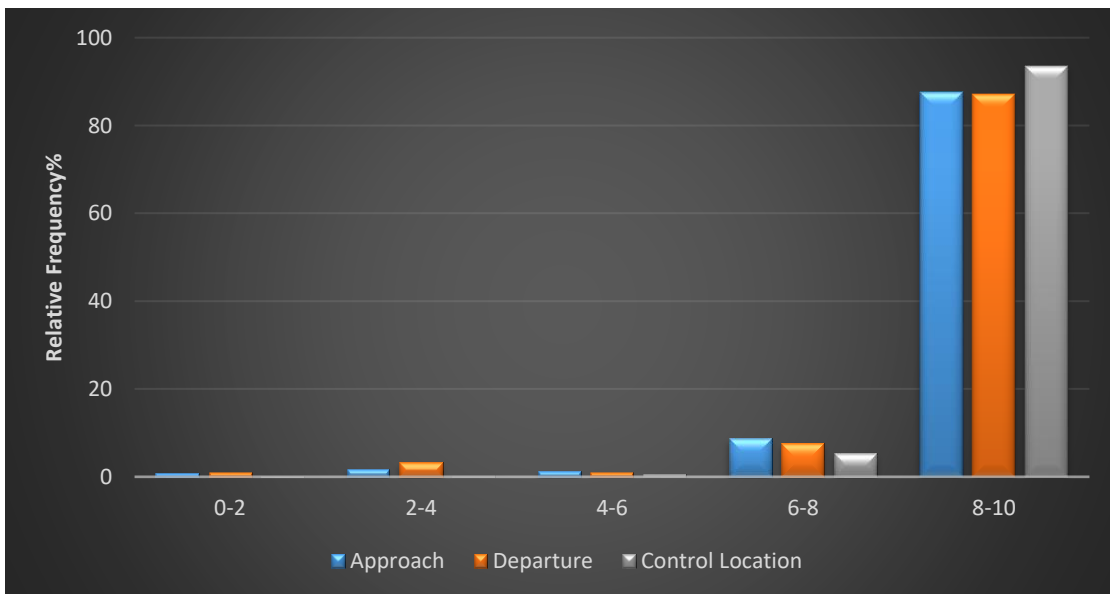


Figure 8 Distribution of Crack Rating (CR)

3.3 Pavement Condition Analysis Based on 2015 Pavement Condition Data

An annual pavement condition forecast is published by FDOT on their website every year. That forecast report contains pavement condition data over the last 16 years for each pavement section. The pavement sections included in that 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 regular roadway pavements, and therefore cannot be used in this study. Instead, a 2015 pavement condition data set with higher section resolution was provided directly by the FDOT State Materials Office. This data set contains pavement condition for each 0.001-mile (5.3 ft.) highway section, in terms of rut depth, IRI, and ride number, and therefore is analyzed in this section.

3.3.1 Evaluation Procedure of Pavement Distresses Based on Condition Data

The beginning and ending mile posts of each of the 1155 bridges included in this study were used to search for the needed pavement condition data from the given data set. Due to data mismatching and missing, only 1013 bridges were identified in the data set. For each bridge, the following steps were followed to evaluate pavement distresses.

First, the starting point of a bridge was identified, as shown in Figure 9. From this point backwards, three rectangular segments were selected. The first segment is the approach slab, and the other two segments (labelled as Approach Segment 1 and 2) are each approximately 95 feet in length and usually 12 feet in width. Similarly, two more segments on the other side of the bridge were selected, including the departure slab and two 95 feet segments (labelled as Departure Segment 3 and 4). Choice of 95 feet 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-mile highway sections, which leads to a length of 0.018 mile (95

feet). The control (regular roadway) section not shown in Figure 9 is usually 0.2 miles away from bridge approach/departure and is 105 feet in length. Pavement condition data from the control sections were used as benchmark for comparison with approach and departure pavement conditions.

Second, the rut depth, international roughness index (IRI), and ride number information was extracted for each bridge approach/departure segment and control section.



Figure 9 Schematic Depiction of Survey Area in one Lane around a Bridge

Third, Rut Rating and Ride Rating were computed for each segment from the rut depth, IRI, and ride number data, following the procedures in FDOT 2015 Flexible Pavement Condition Survey Handbook (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 inches/mile is considered to represent good riding quality (FHWA, 2016).

3.3.2 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 asphalt pavements on bridge approaches and departures.

3.3.3 Overall Analysis and Results

A summary of the three condition indices on bridge approach and departure pavements and at control sections for all the 1013 bridges is presented in Table 2 and Figure 10 through Figure 12. It can be observed from Table 2 that the average Rut Rating is slightly higher on bridge approach or departure pavements than on regular roadways, indicating slightly less rutting on

bridge approaches/departures. The average IRI and Ride Rating values, however, show that the bridge approach/departure pavements are significantly rougher than regular pavements. It may also be observed that the closer to the approach/departure slabs, the rougher the pavement becomes.

Table 2 Average Pavement Condition Indices for All Bridges

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

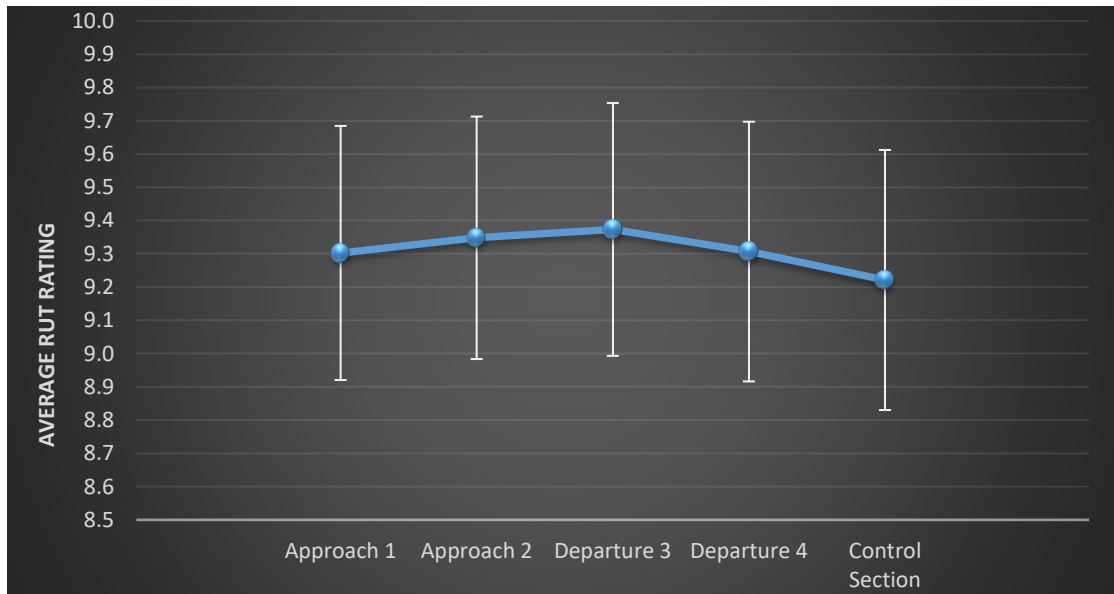


Figure 10 Summary of Rut Rating for all Bridges

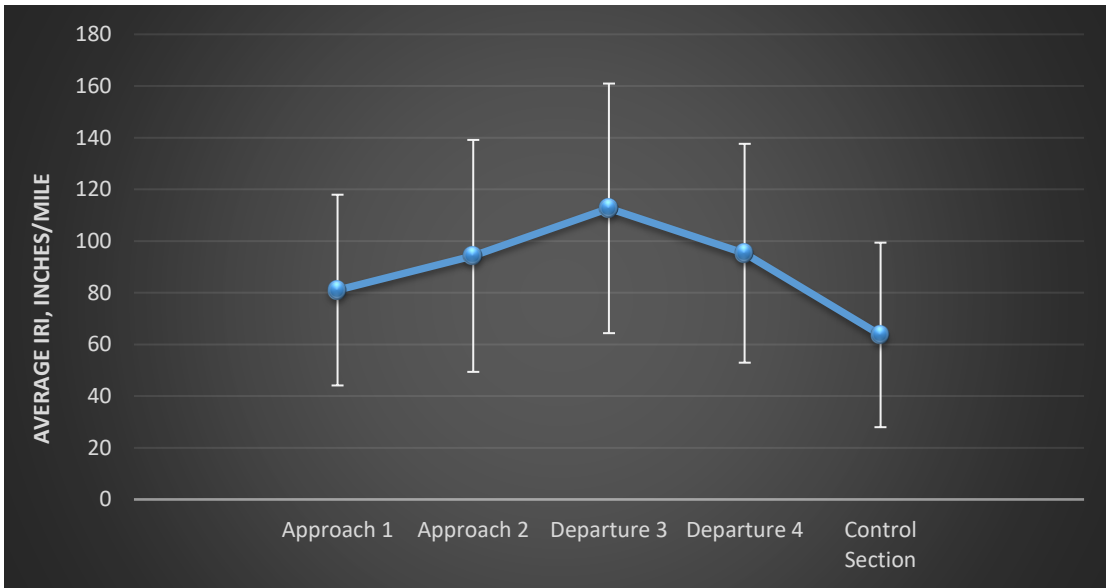


Figure 11 Summary of IRI for all Bridges

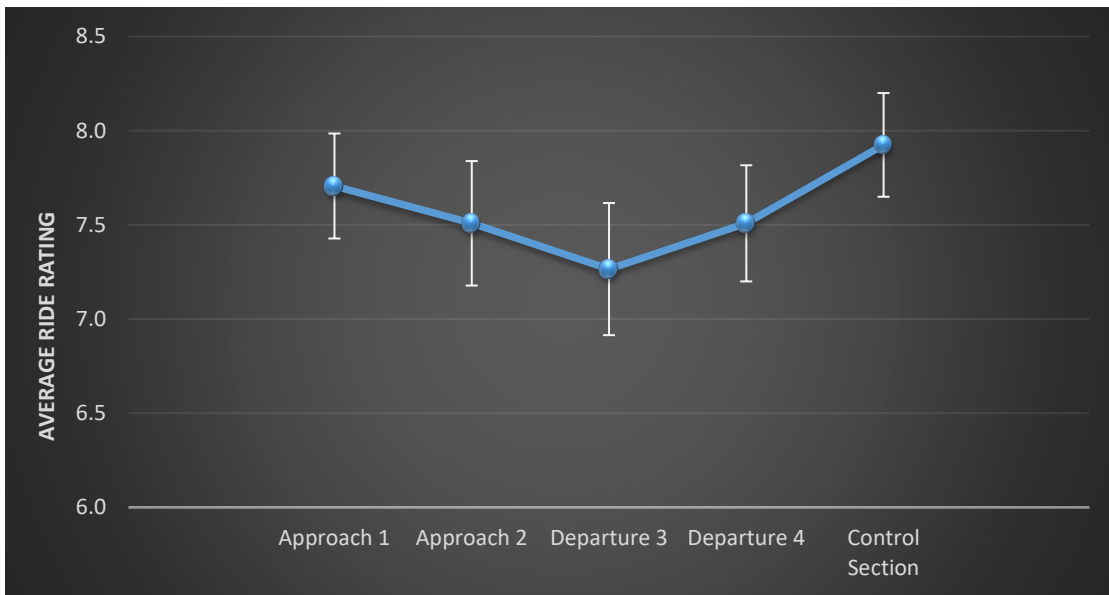


Figure 12 Summary of Ride Rating for all Bridges

Figure 13 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 inches/mile, or Ride Rating greater than 7). It can be seen that out of the 1013 bridges considered, around 200 bridges have noticeable rutting in their approach or departure pavements, but there are around 290 bridges whose corresponding control pavement sections have noticeable rutting. In terms of IRI, around

370 bridge approach pavements and about 540 bridge departure pavements have rough condition (IRI greater than 95 inches/mile), which are significantly more than the number of control pavement sections (around 90). Among all the bridges whose control pavement sections have good riding condition (i.e., IRI lower than 95 inches/mile), about 30% bridges showed worse riding condition (i.e., IRI greater than 95 inches/mile) on their approach pavements, and about 50% bridges showed worse riding conditions on their departure pavements.

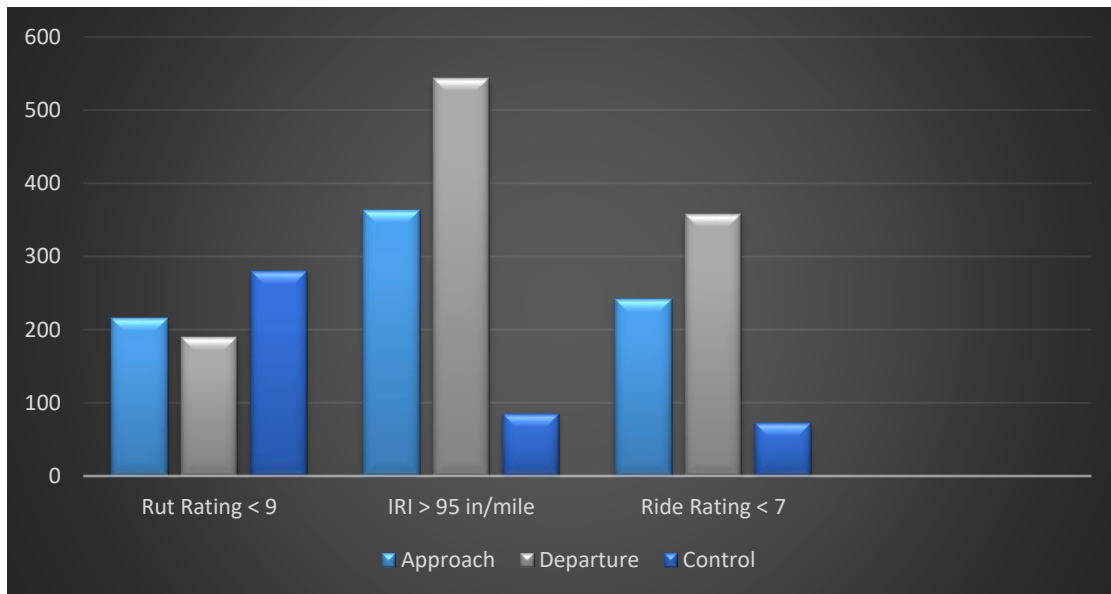


Figure 13 Number of Bridges with Pavement Condition Indices Indicating Distresses

3.4 Asphalt Layer Thickness Analysis

As discussed in the literature review, one of potential causes of distresses is change in thickness of the approach pavement. Moreover, in the nationwide survey it was observed that 30% of the states surveyed had experienced the thin asphalt layer issue on their bridge approach/departure pavements. It is, therefore, worthwhile to investigate the asphalt layer thickness near the bridges analyzed in this study. This is discussed in this section. The correlation between asphalt layer thickness and pavement distress is analyzed statistically in the next chapter.

FDOT does not maintain a statewide highway pavement structure database. Instead, a ground penetration radar (GPR) data set is available from the FDOT State Materials Office. 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 asphalt approach/departure pavements.

3.4.1 Selection Method of GPR Data

The GPR data were recorded at a varying spacing (i.e., pavement section length) on different highways, as summarized in Table 4. For the GPR data recorded at a spacing of 100 feet, 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 feet 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 feet), more data points were used to calculate the average thickness. A control section was selected at a distance of 0.3 mile away from each bridge to calculate the average asphalt layer thickness of regular roadway pavements.

Table 3 GPR Data Point Spacing

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

3.4.2 Asphalt Layer Thickness Trends

The average asphalt layer thicknesses for different pavement sections are shown in Figure 14. It can be observed, for the 113 bridges investigated, the average asphalt layer thickness is

significantly lower (about 2 inches less) on bridge approaches or departures than on regular roadway sections (Control Sections).

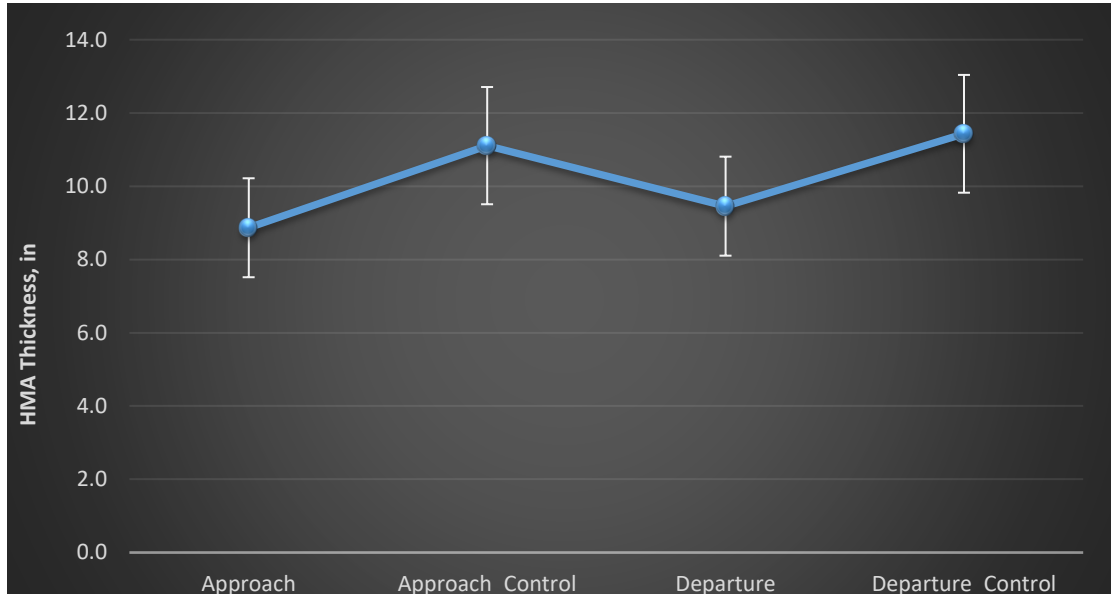


Figure 14 Comparison of Asphalt Layer Thickness

3.5 Summary of Pavement Data Analysis

The conditions of bridge approach and departure asphalt pavements in the outer (truck) lane on FDOT interstate highways were analyzed in terms of one index (Crack Rating) based on video log images, and three indices (Rut Rating, IRI, and Ride Rating) based on pavement condition data.

It is found that generally bridge approach and departure pavements have more cracking distress and higher roughness than regular roadway pavements. The difference in rutting distress, however, is less significant than the differences in cracking and roughness. 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 roughness of a bridge approach/departure pavement generally increases as it gets closer to the approach/departure slab.

Among the 1155 interstate highways bridges with asphalt approach/departure pavements, about 27% bridges showed signs of cracking distress in their approach or departure pavements. About 20% bridges have noticeable rutting in their approach or departure pavements. Among all the bridges whose control pavement sections have good riding condition (i.e., IRI lower than 95 inches/mile), there are about 30% bridges showing worse riding condition (i.e., IRI greater than 95 inches/mile) on their approach pavements, and about 50% bridges showing worse riding conditions on their departure 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 regular roadway sections.

CHAPTER 4: STATISTICAL MODELLING OF BRIDGE APPROACH PAVEMENT DISTRESSES

4.1 The Linear Regression with Random Parameters Model Structure

A linear regression model is used to explore the factors that affect the asphalt pavement distress on bridge approaches, departures, and control sites. Distress measures such as international roughness index (IRI) and rut depth (RUT) are continuous variables, and a linear regression approach suits best for modelling such variables. Since the IRI and RUT values for a pavement section are always positive, using a linear regression model results in the prediction of non-positive values for the distress variables. So, a log-transformation is applied to the distress variables, and the resultant variables are modelled using a linear regression method. In a linear regression model, the dependent variable is expressed as a linear function of exogenous variables as shown in equation (1).

$$Y_i = \ln(y_i) = \alpha_0 + \beta X_i + \varepsilon_i \text{-----} (1)$$

where $i = 1, 2, 3, \dots, n$ is an index for each pavement section, y_i is the observed values for pavement distress measures, α_0 is a constant, β is a vector of estimable parameters, X_i is a vector of exogenous variables and ε_i is a standard normally distributed error term. To account for the heterogeneity in the parameter estimates due to unobserved factors, parameters are assumed to vary across different pavement sections according to a pre-specified distribution. The resultant expression for the dependent variable is shown in equation (2).

$$Y_i = \alpha_0 + \beta_i X_i + \varepsilon_i \text{-----} (2)$$

Assuming that random parameters are normally distributed and $f(\cdot)$ is the probability density function of a normal distribution, likelihood expression for an individual i is expressed in given equations (3) and (4).

$$p(Y_i) = \int p\left(Y_i/X_i; \alpha_0, \beta_i\right) f(\beta) d\beta \text{----- (3)}$$

$$= \int \frac{1}{\sqrt{2\pi}} e^{\left(\frac{-(\ln(y_i) - (\beta_0 + \beta_i x_i))^2}{2}\right)} f(\beta) d\beta \text{----- (4)}$$

The simulated maximum likelihood estimation approach is used to estimate the parameters and 200 Halton draws are used to evaluate the multi-dimensional integral of the likelihood function.

4.2 Other Detailed Data Collected for Modelling

Alligator cracking and rutting are the common pavement distresses observed on bridge approach pavements which compromise roadway smoothness. Based on the FDOT survey reports (Moseley, 2009, 2012, 2013), some bridge approach pavements are much thinner than their adjacent regular pavements. The relationship between bridge approach pavement roughness and inadequate pavement structure needs to be investigated.

To identify the factors influencing bridge approach pavement performance, relevant information was collected from various sources (e.g., FDOT SMO, RCI database, FDOT pavement management reports, GPR survey reports, etc.) and compiled together. The first source is FDOT pavement condition database, which contains roughness data for bridge approach pavements in 2014. The second source is FDOT Roadway Characteristics Inventory (RCI) database, which contains comprehensive roadway information, such as traffic-related information (e.g., AADT, AADTT, and speed limit) and pavement structure information (e.g., base layer type, base layer thickness, and friction course type). The third source is FDOT pavement management reports, which contain information about recent maintenance year for each roadway section. The fourth

source is GPR survey reports, which contain the thickness of pavement surface layer. A total of 68 bridge approaches, bridge departures, and regular roadway pavement sections (control sites) are identified simultaneously.

4.3 Results

This section presents the estimation results of Random Parameters Linear Regression Model (RPLRM) for asphalt pavement distress obtained after extensive specification testing. Pavement characteristics (surface type and thickness, base type and thickness, and pavement age), traffic characteristics (AADT and AADTT), roadway characteristics were tried during the model development. Environment related variables are not included in the modeling since it is assumed that the climate condition is similar across the Florida highway network. Descriptive statistics of variables present in the final linear regression model are shown in Table 4. The estimation results of RPLRM for the IRI and RUT values of the pavement section on bridge approaches, departures, and control site are presented in Table 5 and Table 6, respectively.

Factors influencing the IRI of the approach pavement section are the surface thickness and pavement age. In specific, a section with surface thickness greater than 5 inches is more likely to have higher IRI values, while all else remain the same. Moreover, the approach pavement section with higher surface thickness might have higher IRI values. Such as, a section with higher thickness might result in the height differences between the study section and adjacent section (concrete or regular pavement) and lead to cracking due to the traffic movement. Most importantly, the application of asphalt overlays, milling and digouts on existing conditions comprises a significant effect on the smoothness (Hung, et al., 2014). That is why bridge approach/departure pavements with inadequate and with excess thickness are more likely to experience severe cracking than the regular asphalt Pavement. Thus, a proper design measure is to be followed.

Similarly, with increase in IRI of an approach pavement section the age of pavement results in an increase in the IRI values. Such as, as the age of the section increases, the cracks in the pavement might gradually increase due to its exposure to traffic and adverse weather conditions.

In addition to pavement age and surface layer thickness, it is found that annual average daily truck traffic (AADTT) and pavement friction type have statistically significant effect on the IRI values at the departure pavement section. In detail, a section with pavement course FC2 is more likely to have lower IRI values as compared to the other pavement course types. It is found that a section with AADTT greater than 15,000 is more likely to have higher IRI values as compared to the counter group sections. The same finding is evident from the literature that increase in the truck movements on a pavement section damages the pavement by causing cracks. Whereas for the control sites, AADTT has heterogeneous effect on the IRI values. In specific, only 92.9% of sections with AADTT greater than 15,000 are more likely to have higher IRI values as compared to the other group. Whereas for the rest 7.1% of the sections, the effect is vice-versa.

Moving to the RUT values on a pavement section, surface layer thickness of approach section indicator variable (1 if the surface layer thickness is greater than 5 inches otherwise 0) is found to have heterogeneous effect on the RUT values for approach sections. Approximately for 91% of the approach sections, sections with surface thickness greater than 5 inches is more likely to have higher RUT values as compared to the other group. Similarly, for 75.8% of the sections, as the pavement age increases, it is more likely that the RUT values of a departure pavement section increase. Finally, none of the available variables are found to have statistically significant effect on the RUT values at a control section.

Table 4 Descriptive Statistics of Potential Variables Influencing the IRI or RUT Values of an Asphalt Pavement

Variable description	Mean Value	Standard Deviation	Minimum Value	Maximum Value
<i>Dependent variables</i>				
IRI of Bridge approach pavement (inches/mile)	4.58	0.28	3.64	5.36
IRI of Bridge departure pavement (inches/mile)	4.66	0.29	3.76	5.35
IRI of Control site (inches/mile)	4.25	0.26	3.63	4.96
RUT of Bridge approach pavement (inches/mile)	-3.17	1.40	-7.57	-0.98
RUT of Bridge departure pavement (inches/mile)	-3.06	1.54	-6.88	-0.97
RUT of Control site (inches/mile)	-3.13	1.80	-9.97	-0.94
<i>Independent variables</i>				
Annual average daily traffic (AADT) (25,000 vehicles per day)	0.14	0.35	0	1
Annual average daily truck traffic (AADTT) (15,000 vehicles per day)	0.13	0.34	0	1
Pavement age from the most recent pavement rehabilitation year (years)	7.42	3.40	1	12
Friction course type indicator (1 if friction course of pavement surface layer is friction course 2 (FC-2), 0 otherwise)	0.13	0.34	0	1
Surface layer thickness of bridge approach pavement (inches)	0.70	0.45	0	1
Surface layer thickness of bridge departure pavement (inches)	0.58	0.49	0	1
Surface layer thickness at control site (inches)	0.02	0.17	0	1

Table 5 Estimated Parameters for Bridge Approach and Departure Pavement Roughness Models. (Random parameters are in parenthesis)

Variable Description	Log (IRI on Approach)			Log (IRI on Departure)			Log (IRI on Control site)		
	Parameter	t-statistic	P Value	Parameter	t-statistic	P Value	Parameter	t-statistic	P Value
Constant	4.32	44.81	0.0	4.34	47.03	-	4.25	122.2	0.0
Surface layer thickness of bridge approach pavement indicator (1 if thickness is greater than 5 inches, 0 otherwise)	0.11	1.60	0.11	-	-	-	-	-	-
Pavement age in years	0.02	2.52	0.014	0.03	3.28	0.001	-	-	-
Surface layer thickness of bridge departure pavement indicator (1 if thickness is greater than 8 inches, 0 otherwise)	-	-	-	0.2	1.95	0.05	-	-	-
Annual average daily truck traffic indicator (1 if truck traffic is greater than 15000, 0 otherwise)	-	-	-	0.47	4.31	0.0	0.22 (0.15)	0.23 (1.73)	0.08
Pavement friction indicator (1 if the pavement type is FC2, 0 otherwise)	-	-	-	-0.35	-3.46	0.001	-	-	-
Number of observations	68			68			68		
Log likelihood of constants only model	-9.06			-13.28			-5.75		
Log likelihood at convergence	-5.01			-0.46			-5.52		

Table 6 Estimated Parameters for RUT on Bridge Approach and Departure Models. (Random parameters are in parenthesis)

Variable Description	Log (RUT on Approach)			Log (RUT on Departure)			Log (RUT on Control site)		
	Parameter	t-statistic	P Value	Parameter	t-statistic	P Value	Parameter	t-statistic	P Value
Constant	-4.72	-9.16	0.0	-3.56	-9.97	0.0	-3.0	-5.37	0.0
Surface layer thickness of bridge approach pavement indicator (1 if thickness is greater than 5 inches, 0 otherwise)	1.55 (1.16)	2.95 (12.40)	0.0	-	-		-	-	-
Pavement age in years	-	-		0.07 (0.10)	1.68 (4.64)	0.0	-	-	-
Number of observations	68			68			68		
Log likelihood of constants only model	-119.4			-121.89			-135.67		
Log likelihood at convergence	-117.10			-121.12			-135.67		

CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH

5.1 Conclusions

This study analyzed the factors affecting asphalt pavement distresses on the approaches and departures of highway bridges. There is no such vast body of knowledge, compared of several past studies, concerning the identification of factors contributing to asphalt pavement distresses on bridge approaches/departures. This study dealt on asphalt pavement transitions on bridge approaches/departures on Florida Interstate Highways. Through preliminary survey it was found that there are more distresses in pavements at bridge approaches/departures than regular asphalt pavements.

As part of this study a nationwide questionnaire survey is conducted to collect information from professionals with experience with pavements and bridges so that it would be helpful to investigate the extent and causes of asphalt pavement distresses adjacent to bridge approaches/departures. In this survey over 60% respondents noticed pavement distresses next to bridge approach slabs. About 30% of the states noticed thinner asphalt pavements near bridges when compared to regular pavement sections. In the survey, 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.

An analysis was carried out using pavement condition data to determine the extent of pavement distresses on bridge approaches/departures. The data were collected mainly from two

sources: FDOT highway video log images and pavement condition data. It is found that among the 1155 Interstate Highways bridges with asphalt approach/departure pavements in Florida, about 27% bridges were affected with cracking distress in their approach/departure pavements. About 20% of bridges were identified with rutting distress in their approach or departure pavements. Moreover, among all the bridges whose control pavement sections have good riding condition (i.e., IRI lower than 95 inches/mile), about 30% bridges showed worse riding condition (i.e., IRI greater than 95 inches/mile) on their approach pavements. Similarly, about 50% bridges showed worse riding conditions on their departure pavements. Based on the GPR data of 113 bridges, it was noticed that the average asphalt layer thickness is lower on bridge approaches/departures than that of regular roadway sections.

Finally, a statistical analysis was performed in this study. A linear regression with random parameters model was applied to examine the factors that may influence asphalt pavement distresses. The model was run for pavement roughness and rutting on bridge approaches/departures as well as on control pavement sections. The model considers a comprehensive set of potential determinants of distresses, including pavement characteristics, roadway characteristics and traffic characteristics. The study appears to be the first to compare the effects of variables causing distresses in asphalt pavement transitions next to approach/departure slabs. In the modeling, the non-negative continuous dependent variables, including International Roughness Index (IRI) and rut depth, were log-transformed.

This study focused on the impact of various factors on asphalt pavement transitions next to bridge approach/departure slabs. The scope of the research is limited due to availability of relevant pavement characteristics data. There is room for improving the model specification by including each pavement layer thickness and type of material used, different compaction levels if

there any, detailed roadway geometry, thickness of actual asphalt layer before and after construction.

5.2 Future Research

In future work, it is desirable to identify more detailed factors and develop a statistical model with more independent variables relevant to the distresses in asphalt pavements on bridge approaches and departures. Some variables that are not specifically considered in the statistical modeling in this study due to availability issue may include: the thickness and material type of each pavement layer, compaction level during construction, moisture content and settlement of embankment soil, quality of drainage system, and climate features.

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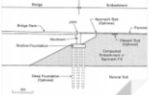
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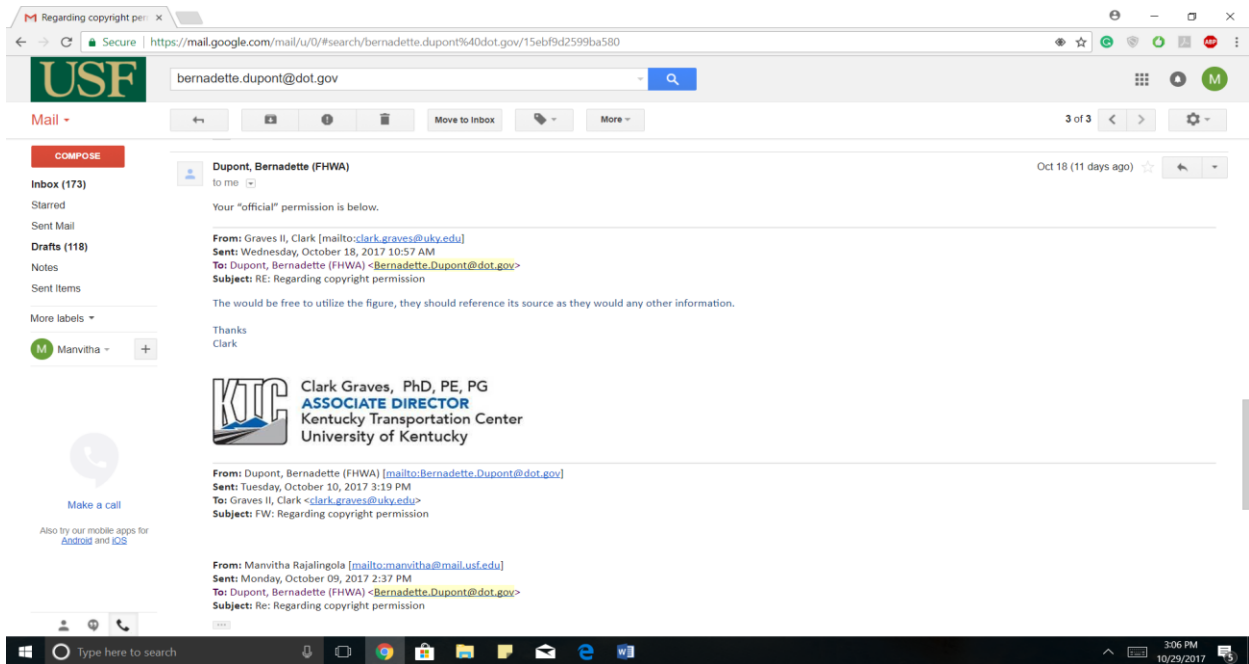


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to me

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