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Jiwen Zhang, Student Dr. Timothy R.B. Taylor, Major Professor Dr. Yi-Tin Wang, Director of Graduate Studies

BRIDGE END SETTLEMENT EVALUATION AND PREDICTION

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Engineering at the University of Kentucky

By

Jiwen Zhang

Lexington, Kentucky

Director: Timothy R.B. Taylor, Professor of Civil Engineering Lexington, Kentucky 2016

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ABSTRACT OF DISSERTATION

BRIDGE END SETTLEMENT EVALUATION AND PREDICTION

A bridge approach is usually built to provide a smooth and safe transition for vehicles from the roadway pavement to the bridge structure. However, differential settlement between the roadway pavement resting on embankment fill and the bridge abutment built on more rigid foundation often creates a bump in the roadway. Previous work examined this issue at a microscopic level and presented new methods for eliminating or minimizing the effects at specific locations.

This research studies the problem at a macroscopic level by determining methods to predict settlement severity to assist designers in developing remediation plans during project development to minimize the lifecycle costs of bridge bump repairs. The study is based on historic data from a wide range of Kentucky roads and bridges relating to bridge approach inspection and maintenance history. A macro method considering a combination of maintenance times, maintenance measures, and observed settlement was used to classify the differential settlement scale as minimal, moderate, and severe, corresponding to the approach performance status good, fair, and poor. A series of project characteristics influencing differential settlement were identified and used as parameters to develop a model to accurately predict settlement severity during preliminary design. Eighty-seven bridges with different settlement severities were collected as the first sample by conducting a survey of local bridge engineers in 12 transportation districts. Sample two was created by randomly selecting 600 bridges in the inspection history of bridges in Kentucky. Ordinal and/or multinomial logistic regression analyses were implemented to identify the relationships between the levels of differential settlement and the input variables. Two predictive models were developed. Prediction of bridge approach settlement can play an important role in selecting proper design, construction, and maintenance techniques and measures. The users can select one or two models to predict the approach settlement level for a new bridge or an existing bridge with different purposes.

The significance of this study lies in its identification of parameters that had the most influence on the settlement severity at bridge ends, and how those parameters interacted in developing of a prediction model. The important parameters include geographic regions, approach age, average daily traffic (ADT), the use of approach slabs, and the foundation

soil depth. The regression results indicate that the use of approach slabs can improve the performance of approaches on mitigating the problem caused by differential settlement. In addition, current practices regarding differential settlement prediction and mitigation were summarized by surveying the bridge engineers in 5 transportation districts.

KEYWORDS: bump at the end of the bridge, bridge approach, differential settlement, approach slab, prediction model, logistic regression

Jiwen Zhang Student's Signature

4/27/2016

Date

BRIDGE END SETTLEMENT EVALUATION AND PREDICTION

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4/27/2016

Date

To my parents, wife, and the coming baby.

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1 INTRODUCTION

1.1 Background and Motivation

The differential settlement (also referred to approach settlement) between the bridge abutment and the adjacent roadway pavement usually creates a bump in the roadway. This differential settlement is commonly defined as "the difference in elevation of approach pavements and bridge upper-structures caused by unequal settlement of embankments and abutments." (Sam Helwany et al., 2007). Settlement of the approach is an old and well recognized problem across most of the state transportation agencies. The Kentucky Transportation Cabinet (KYTC) has also identified bridge settlement and the formation of the bump as a significant problem due to its noticeable consequences. This heave/uneven transition may cause the following results:

- a) discomfort to passengers,
- b) damage to vehicles,
- c) a negative effect on public perception of the state infrastructure,
- d) damage to bridge structures,
- e) reduced steering control for drivers,
- f) increased traffic loading on the abutment,
- g) accidents,
- h) considerable maintenance costs/works, and
- i) delays and inconveniences caused by maintenance work.

In addition, the constant maintenance work, closure of lanes, traffic control resulted by bump problems would adversely interrupt the orderly flow of traffic and cause delay; or in some cases the maintenance works in heavy traffic roads are practically impossible without bringing traffic into a standstill. According to the report of Federal Highway Administration (FHWA) "Priority, Market-Ready Technologies and Innovations" (FHWA-HRT-04-053), the delay hours caused by traffic congestion due to road repair works average approximately 36 hours for each person per year. In other words, all kinds of repair work results in annually 5.7 billion of person-hours of delay. Maintenance work of bridge bumps takes up an important part of the whole amount of repair works for transportation agencies, and hence bump problems have gained more attention especially in this era where time is becoming more and more valuable to everybody.

Considerable amounts of annual maintenance cost to reduce differential settlement and bump problems consume a significant amount of budgets of state departments of transportation in the United States. National Cooperative Highway Research Program (NCHRP) synthesis 234 (Briaud et al., 1997) reported that 25 percent of the bridges nationwide, approximately 150,000 bridges, showed damage induced by differential bridge approach settlement and more than \$100 million is spent on maintenance or repair every year. A survey (Laguros et al., 1990) of 61 different transportation agencies concluded that almost 70% of the agencies considered bridge approach settlement or bump problems significant. Furthermore, a more detailed survey (Hoppe, 1999) reported that bridge approach settlement or bump problems were rated as a significant problem by 44% of the state Department of Transportation agencies (Figure 1.1). Kentucky is listed as having a "Yes" problem. Furthermore, interviews with the local bridge engineers also

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conclude that the bridge approach settlement is extensive in Kentucky. Statistics gathered from KTC (Dupont and Allen, 2002) reported that nearly \$1000 is spent per bridge per year to address approach settlement problems, slightly higher than the national average cost of \$700 per bridge per year (Briaud et al., 1997).



Figure 1.1 The significance of bridge approach settlement (Virginia DOT, 2003)

A survey concerning the validity of using approach slab as one of the most effective measures for eliminating differential settlement at bridge ends was also conducted by Virginia DOT in 1999. The results as showed in Table 1.1 indicate that almost half states still consider the approach slab settlement as a significant problem.

State	Yes	No	Moderate
AZ		X	
CA	X		
СТ			X
DE	X		
FL			X
GA	X		
ID	X		
IN			X
IA			X
IL	X		
KS	X		
KY	X		
LA	X		
MA			X
MD			X
ME		X	
MI			X
MN	X		
MS	X		
МО	X		
MT	X		
ND	X		
NE	X		
NH		X	
NJ			X
NM	X		
NY			X
OH			X
ОК	X		
OR	X		
SC	X		
SD	X		

 Table 1.1 Is Approach slab settlement a significant problem? (Virginia DOT, 1999)

TX		Х	
VT		Х	
VA			Х
WA	Х		
WI	Х		
WY		Х	

Because of the serious consequences caused by differential settlement, numerous studies have been funded to identify the mechanism of the formation of approach settlement, determine the mitigation methods, and seek advanced maintenance techniques to lessen maintenance budget. In an effort to reduce the effects of differential settlement, the present research is primarily aimed at developing a model that can predict settlement and determine remediation plans during project development based on given project characteristics. With this core objective in mind, one of the tasks of this research is to synthesize the causation of differential bridge end settlement and bump problems in Kentucky and then identify best practices to prevent differential settlement.

1.2 Definition of the "Bump" and Rating

Differential settlement originates from the fact that the bridge transition connects two structures with different supporting systems. A bridge abutment is usually constructed on relatively firm soil, rock, or piles driven to a dense or stiff deep soil stratum and generates slight settlement, which is negligible compared to the settlement of roadway pavement that is commonly supported on a natural or filled soil subgrade.

The "bump" typically can be defined as the differential settlement at the area between the bridge and roadway interfaces (Anand J., 2009). Differential settlement is an occurrence

ordinarily discovered where two foundations of two cooperating structures have been constructed under different concepts. For roadways, this occurrence can be found at the intersection between the roadway and the bridge, which is normally indicated as approach pavement/slab in the most cases. White et al. (2005) defined the term "bridge approach" as a larger area covering from the bridge structure/abutment to a distance of about 100 ft. away from the abutment. This definition refers to not only the approach slab alone but also the backfill and embankment areas beyond and under the approach slab as significant factors that contribute to the settlement around the bridge approach region.

Many researchers have studied the interface between bridge and roadway. Four methods have been summarized to define the approach settlement tolerance.

a) Bump could be noticed with about 0.5 inches of approach settlement (Wahls, 1990), and may cause riding discomfort at about 2 to 2.5 inches (Stark et al. 1995). Walkinshaw (1978) suggested the differential settlement greater than 2.5 inches can result in a poor ride quality and maintenance is needed. Bozozuk (1978) concluded that differential settlement could be tolerated to 3.9 inches vertically and 2 inches horizontally. Hun Soo Ha et al (2002) suggested a range to rate the bump scale.

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Rating	Description	Range
0	No Bump	0
1	Slight Bump	~1 inch
2	Moderate Bump—Readily Recognizable	~2 inch
3	Significant Bump—Repair Needed	~3 inch
4	Large Bump—Safety Hazard	>3 inch

 Table 1.2 Bump Scale Ratings (Hun Soo Ha, 2002)

- b) Long et al. (1988) and Wahls (1990) recommended the use of a relative gradient, which is defined as a function of the length of the approach slab, of 1/125 as a criterion to begin a remedial action, and a gradient smaller than 1/200 may be considered as a satisfactory level for rider comfort. According to these thresholds, the required design length of an approach pavement/slab (*L*) can be estimated as: $L \ge 200(sf - sa)$, Where *sf* is the estimated total fill settlement at the end the approach pavement/slab, and *sa* is the estimated settlement of the bridge abutment.
- c) Several researchers used the International Roughness Index (IRI), which is defined as the accumulations of undulations under a given segment length and normally in the form of mm/m or m/km, to determine the allowable bumps. The highest IRI value would be used to rate the performance of an approach, and rating system of bridge approaches using IRI was developed by Louisiana Transportation and Research Center (LTRC) (Das et al. 1999).

Range (IRI) m/km	Rating
0 to 3.9	Very Good
4.0 to 7.9	Good
8.0 to 9.9	Fair
10.0 to 11.9	Poor
12 and above	Very Poor

 Table 1.3 Approach slab rating system developed by LTRC (Das et al. 1999)

d) In Australia, Hsi (2007) recommended differential settlement of 0.3 percent, grade change in transverse and longitudinal direction, and a residual settlement of 100 mm for a 40-year period as threshold to initiate maintenance procedures on transition zones.

1.3 Dissertation Objectives and Tasks

The Kentucky Transportation Cabinet (KYTC), and many other state transportation agencies, continually struggle with differential settlement at bridge ends. Bump issues present a potential hazard at bridge ends for motorists, particularly motorcyclists. Additionally, bump issues are a constant source of maintenance spending, averagely \$1,000 per bridge per year in the commonwealth of Kentucky (Dupont and Allen, 2002). Many have deemed that it is a problem that is going to exist without resolution from some configurations of approach slabs, flooded backfills, or any other methods. This research does not study bump issues from the angle of developing engineering techniques that may minimize or eliminate the differential settlement at bridge ends. In contrast, this study aims to identify the best practice of minimizing or eliminating bump issues by analyzing other states' experience regrading this issue and attempts to yield a model for estimating the severity of the phenomenon given specific project conditions based on nearly 50 years of highway and bridge construction in Kentucky. In this way, the transportation agency can be prepared to monitor and better repair the situation when it occurs.

The main objective of this research project is to develop a settlement predictive model at a macro level for estimating the severity of differential settlement at bridge ends. Therefore, it is significant to identify major project characteristics that have an important impact on the formation of the approach settlement, and determine which characteristics could be qualitative or quantitative defined and regarded as inputs to build the model. This methodology intends to provide project stakeholders with an overall understanding of monitoring and better repairing the differential settlement at bridge ends when it occur. With this view in mind, the objectives of the study can be outlined as follows:

- a) Collect a body of design, construction and maintenance data that describes a relevant section of bridges and approaching roadways within Kentucky and the bridge end settlement that has occurred at these bridges,
- b) Identify recent developments in research associated with bridge ends, particularly those completed since the last study conducted by KTC,
- c) Analyze the collected macro data and conduct field interviews with each district to identify a subset of bridges and develop a predictive model for bridge end settlement during project planning and design.

1.4 Research Structure

This research can be accomplished through the following tasks:

- a) Review literature and publically available data in differential bridge end settlement and prediction. An extensive literature review related to causation of differential bridge end settlement should be completed in this phase. The review includes publically available resources for existing structures exhibiting differential bridge end settlement (geotechnical reports, project plans, United States Geological Survey, etc.), especially review literature related to prediction of differential bridge end settlement.
- b) Survey selected bridge approaches and qualitatively assess causative factors. An online survey form has been created by "Surveygizmo" to contact district engineers in the 12 districts to identify bridges within their districts that experience excessive approach settlement, moderate approach settlement, and minimal approach settlement, respectively. Project characteristics and geotechnical conditions of these bridges are also requested. Approximately 35 district bridge engineers responded to this survey, as well as more than 130 bridges with different approach settlement levels were collected. These bridges will be verified and used as the first sample to conduct regression analysis in the following tasks. Next, field interviews with each district representatives would be scheduled to verify the results of the survey and acquire an understanding of the whole picture of bump issues at each district.

Advice on how to select bridges is expected, as well as advice on which bridges can be used as sample to conduct regression analysis.

- c) Develop a multivariate regression model for prediction of approach settlement.
- d) Collect the best practices in the treatment of bridge approach settlement. This phase will review literature on best practices for corrective methods in treating differential bridge end settlement. Then collect KYTC practices used as corrective actions for treating the field interview with local district bridge engineers. Lastly, based on previous studies, collect KYTC methods to determine the timing for corrective measures.
- e) Develop a framework for application of settlement treatments to align with predicted settlement conditions. Based on the differential settlement prediction model, the future or past bump problems could be predicted into three levels-severe, moderate, and minimal given a specific bridge. Then, compare this predicted level with the real bump conditions obtained by field interview to verify the validity of this model. If the correlation coefficient of this model is good, it can be used to develop a framework for prescriptive correction measures that could be applied to predicted differential settlement. In addition, procedures and implementation measures for using the framework also should be given.

1.5 Dissertation Significance

This research expects to obtain a comprehensive picture of current bump problems in Kentucky. Identify design, construction, and maintenance practices to eliminate or minimize the differential settlement at bridge ends according to previous study review, survey, and field interview with local bridge engineers in each district. Different variables that contribute to the formation of approach settlement would be identified and defined. Some bridges that have been experiencing different settlement levels would be asked from local bridge personnel according to a survey, which would generate the first sample with small quantity of bridges. Then the second sample with 600 bridges would be created by randomly selecting bridges from the inspective datum of Kentucky to conduct logistic statistical analysis to develop models for predicting the settlement status. Availability and reliability of these two models would be compared and verified. Next, develop an implementation resource to use as a model to predict bridge end settlement given project conditions and provide a framework for application of settlement treatments to align with predicted settlement conditions.

Numerous studies have been done on the topic of bridge bump issues; some of them were based on the theme of statistics. However, few researchers conducted the analysis according to systematic statistical method. Laguros and Zaman (1990) have established a linear numeric model to explain the relationships between the approach settlement and various causative factors by quantitatively defining these factors, but none of the categorical causing factors were included in this model. Most of previous studies on bump issues focused on only one contributing factor or some and did not study this issue account for all causative factors; or specific techniques for eliminating or minimizing the effects at specific locations/bridges; or conclusions were not based upon an in-depth statistical approach. This study focuses on the issue at a macro level and will develop a settlement predictive model by considering important factors based on historic data from a wide range of Kentucky roads and bridges. This work hopes to offer contributions to

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researchers, engineers, and policy makers. Researchers and engineers will benefit from developing a rich understanding on the mechanism of formation of approach settlement and effective mitigation methods under different circumstances. In addition, this work will offer policy makers insight into effectively initiating guidelines on bridge design, construction, and maintenance work in order to minimize or eliminate approach settlement at bridge ends.

2 LITERATURE REVIEW

In order to appreciate the causes of the failures occurring at bridge ends and to determine the best practices for solving bump problems, a good understanding of the mechanics of approach is warranted. A comprehensive literature review related to the causation of differential bridge ends settlement has been conducted, and general corrective actions for minimizing/eliminating this problem have been summarized. This section is aiming at providing a reference when a specific problem has emerged given Kentucky construction policies and project characteristics

2.1 Causes of Bridge Approach Settlement

Many studies (Hopkins, 1969, 1985; Stewart, 1985; Greimann et al., 1987; Laguros et al., 1990; Kramer and Sajer, 1991; Ha et al., 2002; Jayawickrama et al., 2005; White et al., 2005, 2007, Puppala, 2009; AKM, A. I., 2010) have been undertaken to determine causes of the problem. A commonly accepted study conducted by Briaud et al. (1997) summarized various factors that contribute to differential settlement at bridge ends.





the	bridge	ends	(Briaud	et al.	1997)
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Helwany (2007) classified different factors into five major categories. A summary of

these factors is listed in Table 2.1.

Table 2.1	Summary of	causes of bridge	approach settlement	(Helwany, 2007)	
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	Category	Causes
1 Poor 1 Appr	Poor Performance of	Deformation in Flexible Pavement: Rutting, shoving or cracking
	Approach Pavement	Failures in Concrete Pavements: transverse cracking, joint faulting, corner breaks, or blowup
		Improper placement of roadway grades

		Lack of maintenance of expansion joints of Non-
		Integral Abutments causing temperature induced
		stresses on bridge abutment
	Type of Bridge	Ratcheting or cyclic movement of integral
2	Abutments and	abutments resulting in lateral movement of
	Foundation Support	abutment and increased lateral earth pressures
		Vertical movement of foundations (shallow vs.
		deep) in relationship to embankment stiffness
		Improper Abutment or Wingwall Design
		Inadequate compaction of backfill due to limited
		space, improper construction equipment, contractor
		care, soil type, and/or lift thickness
		Volumetric changes of backfill due to temperature
	Vertical and Lateral	differences and drainage (i.e., frost heaving, thaw,
3	Deformation of	collapsible soils, and swelling)
	Backfill	Post-construction consolidation of cohesive soils
		due to the embankment self-weight, traffic loads,
		and weight of asphalt overlays
		Bearing capacity failure of sleeper slab footing
		under approach slabs
		Lateral squeeze of weak foundation soils due to
		increase vertical stresses (i.e., embankment weight)
	Vertical and Lateral	Consolidation settlement (primary & secondary) of
4	Deformation of	silt, clay and organic soils due to increased
	Foundation Soil	effective stress
		Slope stability failures due to soils with low shear
		strengths

		Erosion of side slopes at abutment causing
		localized movements of backfill behind and in
		front of abutment. Also, loss of fines through the
		granular construction layer/pad below the abutment
		(usually constructed to facilitate construction
		operations) and the subsequent movement due to
5	Door Droing go	fines migration
5	Foor Drainage	Instability of slopes at the abutment from rise in
		water level
		Increase in hydrostatic pressure behind abutment
		Poor pavement drainage causing ice lensing, soft
		subgrades, and
		pumping that causes faulting in concrete
		pavements and cracking in flexible pavements

Puppala (2009) presented the following major factors that caused approach bumps by summarizing and reviewing of other investigations that addressed the bump problems:

- Consolidation settlement of foundation soil;
- Poor compaction and consolidation of backfill material;
- Poor drainage and soil erosion;
- Types of bridge abutments;
- Traffic volume;
- Age of the approach slab;
- Approach slab design;
- Skewness of the bridge; and
• Seasonal temperature variations.

Although it is easy to spot excessive settlement at bridge approaches, their causes are usually complex and difficult to figure out. Some studies attempted to solve this problem by addressing one or several causes. In general, approach settlement is a result of a combination of several factors that may vary from case to case. Very seldom can approach settlement be traced to a single cause.

2.2 Mitigation Methods

In order to control or prevent problems induced by differential settlement, numerous mitigation methods have been considered. Most studies give similar recommendations for reducing or removing the effects of approach settlement. In general, mitigation methods can be classified into three major categories of improvements that correspond to the major contributing factors at bridge ends:

- a) enhancement of the foundation soil;
- b) improvement of the embankment fill; and
- c) erosion reduction.

Helwany (2007) summarized mitigation methods that have been used in an attempt to alleviate various factors that may cause approach settlement. One or more of mitigation techniques may be required because of different site conditions.

Causes	Mitigation Method			
	Removal and Replacement of Weak Foundation			
Enhancement of the	Soils			
foundation soil	Ground Improvement (mechanical or chemical)			
	Surcharging			
	Supporting Embankment on Deep Foundations			
	More Stringent Backfill and Compaction			
	Specification			
	Scheduling a Delay in Construction Work			
Improvement of the	Geosynthetic Reinforced Earth			
embankment fill	Controlled Low Strength Materials (CLSM)			
	Lightweight Fills			
	Reinforced Concrete Approach Slab			
	Hydraulic Fills			
	Flatter Side Slopes			
	Limiting P200 material			
	Diverting Water away from the Abutment			
	Geotextile Separators			
Erosion reduction	Backfill and Surface Drains			
	Increasing Surface Drainage			
	Maintaining Watertight Joints			
	Extending Wingwalls			
	Extending Limits of Backfill Prism			

Table 2.2 Mitigation methods of bridge approach settlement (Helwany, 2007)

Although approach settlement has been commonly recognized, given plenty of attention, and its causes have been clearly identified in the past several decades, no unified set of engineering solutions has been proposed primarily due to the complexity of the factors involved and varied situations case by case. Most previous research examined the bump issues at a micro level and presented new engineering techniques for minimizing or eliminating the effects at specific locations. However, the proposed research focuses the problem at a macro level and aims at providing guidelines to stakeholders for a specific project by the development of a settlement predictive model to evaluate the severity of approach settlement.

2.3 Application of Approach Slabs

One of the most popular measures to solve bump problems is the application of approach slabs. Approach slabs refer to reinforced concrete slabs supported at one end on the bridge abutment and at the other end on the embankment fill, and aim to provide a gradual smooth transition or a ramp to span the problematic area between the roadway pavement and bridge structures. The schematic design of an approach slab is illustrated in Figure 2.2. A sleeper slab is sometimes used as a footing that extends the entire width of the roadway to equalize settlement beneath the roadway end, particularly in the case of Portland cement concrete pavements (Hoppe, 1999). Briaud (2002) summarized the function of an approach slab as:

- to span the void that may develop below the slab;
- to prevent slab deflection, which could result in settlement near the abutment;
- to provide a ramp for the differential settlement between the embankment and the abutment. This function is affected by the length of the approach slab and the magnitude of the differential settlement; and
- to provide a better seal against water percolation and erosion of the embankment

A survey (Schaefer and Koch, 1992) showed that 80 percent of new bridges would use approach slabs across the United States. Hoppe (1999) concluded that the frequency with which approach slabs are used varies drastically throughout the nation. 14 DOTs use approach slabs at all times for conventional abutments, while Kentucky is one of the only two DOTs (the other one is Maryland) that claims that approach slabs serve only to move the bump from the end of the bridge to the end of the approach slabs and practices a nouse policy. Obviously, there is no direct correlation between the application of approach slabs and the alleviation of bump effects, because no consensus has been obtained on the real benefits or drawbacks with regard to the use of approach slabs. Table 2.3 shows the percentage of approach slabs that are used in various states on interstate, primary, and secondary systems. It is evident that the use of approach slabs on the primary highway systems is prevalent, while Kentucky's response indicated that usage of approach slabs on interstate and primary systems is dramatically below the national average and also indicated low usage on secondary roads compared with most of other states. Hoppe (1999) also conducted a survey on the advantages and disadvantages of using approach slabs. Smooth ride, reduced impact on the backwall, and enhanced drainage control are commonly considered as the major benefits of approach slabs. On the other hand, initial high construction cost and maintenance problems with settling approach slabs are quoted as the main disadvantages. The reasons that no clearly defined benefits from the application of approach slabs was indicated by Kentucky will be investigated in this study. The primary benefits and drawbacks of using approach slabs are summarized in Table 2.4 and Table 2.5.



Figure 2.2 Schematic design of a typical approach slab (TxDOT, 2002)

Table 2.3 Current use of approach slabs (%) state interstate system, primary

State	Interstate	Primary	Secondary	
State	System	System	System	
AL	100	100	20	
AZ	100	100	80	
СТ	< 50	< 50	< 50	
DE	90	65	20	
FL	100	100	100	
GA	100	100	100	
ID	small	small	very small	
IL	100	100	90	
IN	100	100	100	
IA	100	75	10	
KS	90	50	20	
KY	35	35	35	
LA	100	100	100	
ME	>50	>50	>50	

system, and secondary system (Hoppe, 1999)

MD	<1	<2	0
МА	100	100	100
MN	90	69	8
МО	100	100	10
MS	100	100	85
MT	<5	<5	<1
NE	100	100	100
NV	100	100	100
NH	95	30	7
NM	80	80	80
NY	100	100	100
ND	75	60	0
ОН	100	95	75
ОК	100	>90	0
OR	100	100	100
SC	100	100	30
SD	95	90	5
VT	100	100	100
VA	98	75	< 4
WA	75	50	25
WI	100	100	25
WY	90	75	50

	Smooth	Reduced	Control	Uniform	Lower	Calamia	Minimum	
State	Ride	Impact	Drainage	Settlement	Maint.	Seismic	Deviation	None
					Cost	Stability	at Joints	
AL	Δ	Δ						
AZ	Δ	Δ						
CA	Δ							
СТ	Δ							
DE	Δ							
FL	Δ							
GA	Δ							
ID		Δ		Δ				
IL			Δ	Δ				
IN	Δ			Δ				
ΙΟ	Δ	Δ					Δ	
KS	Δ	Δ	Δ					
KY								Δ
LA		Δ						
ME	Δ	Δ		Δ				
MD								Δ
MA	Δ							
MN	Δ	Δ						
MS	Δ							
MO	Δ					Δ		
MT	Δ	Δ						
NE	Δ		Δ	Δ	Δ			
NH				Δ				
NJ	Δ	Δ						
NM	Δ							
NY	Δ							

 Table 2.4 Advantage of Using Approach Slabs (Hoppe, 1999)

ND	Δ				Δ		
OH	Δ						
OK	Δ						
OR	Δ		Δ	Δ		Δ	
SD	Δ	Δ	Δ				
TX	Δ						
VT	Δ	Δ					
VA	Δ	Δ		Δ			
WA	Δ					Δ	
WI	Δ	Δ			Δ		
WY		Δ	Δ	Δ			

	Higher	Maint.	Erosion	Bending	Problems		Douch	Increased
State	Initial			Stress at	w/Staged	Joints	oints	Construction
	Cost			Backwall	Construction		Surface	Time
CA	Δ							
DE	Δ	Δ	Δ					
GA		Δ	Δ					
IL	Δ							
IN	Δ							
ΙΟ	Δ	Δ						
KS	Δ	Δ						
KY	Δ	Δ						
LA				Δ				
ME	Δ							
MN		Δ						
MO	Δ					Δ		
MT		Δ	Δ					
NE	Δ	Δ						
NJ		Δ						
ND	Δ							
OK	Δ							Δ
OR	Δ						Δ	Δ
SD	Δ	Δ						
VA		Δ	Δ					
WA	Δ				Δ			
WI	Δ	Δ						
WY	Δ							

Table 2.5 Disadvantage of using approach slabs (Hoppe, 1999)

It is a consensus that the usage of an approach slab cannot influence the magnitude of the differential settlement that will ultimately develop. In other words, embankment fill settlement would still occur even though approach slabs are used. In that situation, a void may be formed mainly due to soil erosion and fill deformation beneath the approach slab, and approach slabs would play a role as beams that provide smooth transitions between roadway pavement and bridge structures. A study (Zaman, 1990) concluded that approach slabs may alleviate bump problems to some extent in the short run. However, in the long run, the bump problem would get worse in the scenario that the void beneath the approach slabs is so big that they cannot experience the vehicle load due to fractures.

Another debate refers to a subject of when to initiate an approach slab, including design and construction details in various site conditions. Martin et al. (2013) considered that the structural design and construction issues, besides geotechnical in nature, have an important impact on the performance of approach slabs, and a basic design of approach slab is recommended. Most think whether an approach slab would be used or not primarily depends on traffic volume and/or functional classification of the road. A couple of factors are involved in approach slab usage criteria but no consensuses have been reached. Improper design policies may generate two opposite results: if approach slabs are overdesigned, over-expenditure would be burdened; otherwise, cracking or complete failures of approach slabs due to insufficient reinforcement in the long term may cause an abrupt gradient. Due to the complexity of geotechnical conditions of different sites, pavement techniques, and joint expansion at approach slab ends, design and construction of approach slabs are being studied to achieve an equilibrium. Kentucky Structural Design Manual (2005) stipulates a general design criteria of approach slabs and states

that approach slabs should be used as directed by a project manager, however, no standard drawings or detailed design policies of approach slabs have been given and no issues have been indicated on when to initiate an approach slab. A survey conducted by Allen et al. (2002) indicated that only 5 out of 12 districts often place the approach slabs below grade as a prevention technique and only 2 districts have the experience in using sleeper slabs, which is dramatically below the national average. In an effort to further understand the two debatable subjects, effectiveness of approach slabs on mitigating the differential settlement is evaluated by statistical analysis between bridges with approach slabs and bridges without based on a large amount of bridges in Kentucky.

2.4 Critical Review of Previous Studies

To provide detailed background information describing previous studies related to this topic, and to better understand the mechanisms leading to the formation of bridge approach settlement problems, an extensive literature review of previous major research was conducted. Because of the considerable cost spent on mitigating/eliminating bridge approach settlement, Federal Highway Administration (FHWA) and State Department of Transportation(s) (DOTs) have sponsored substantial studies to identify the causes, mitigation measures, and maintenance techniques on the topic of bridge approach settlement or bump problems at the ends of the bridge. Various state DOT studies in the last 50 years have been collected and major works of these studies are listed in Appendix A.

3 DATA COLLECTION

3.1 Model Inputs Identification

As it is shown in the literature review, it is clear that a variety of opinions persists as to the causes of bridge approach settlements and mitigation methods. In order to obtain comprehensive and meaningful relationships between approach settlement levels and various contributors, it is necessary to identify as many initial causing factors as possible because no consensuses have been reached on the role of each factor affecting the final approach settlement formation. In other words, all contributing factors need to be collected and analyze to see the weight of each variable to the predictive model, and then select some of them to establish the optimum predictive model. A series of potential variables is identified and its collection methods are presented. The main model inputs include: (i) bridge length, width, and approach year; (ii) approach type; (iii) abutment type; (iv) embankment fill material and height; (v) foundation soil type (consistency) and thickness; (vi) transportation districts; (vii) Average Daily Traffic (ADT); (viii) drainage.

1. Basic project information

The basic quantitative variables that could be identified include bridge length, width, approach year (year built), and ADT. The age of the bridge approach could negatively affect the embankment fill performance in terms of controlling deformation underneath the approach, especially at the expansion joints next to the slab for those bridges with approach slabs (Laguros et al., 1990 and Bakeer et al., 2005). Traffic volume has been considered as a major factor in the performance of the bump severity, while the opinions regarding the effects of

traffic volume are divergent. High volume traffic has been found to be a compelling reason for the formation of approach settlement (Wong and Small, 1994). On the one hand, Lenke (2006) concluded that bump severity was found to increase with vehicle velocity, vehicle weight, especially heavy truck traffic, and ADT. On the other hand, Bakeer (2005) noted that speed limit and traffic volume almost have no effect on the performance of bridge approaches.

2. Approach Type

The bridge approaches are classified into two categories: (i) bridges with approach slabs or Portland cement concrete approaches are termed as rigid; (ii) bridges without approach slabs or approach built with asphaltic concrete cement are termed as flexible. Evaluation of approach slabs effect on mitigating differential settlement at bridge ends will be investigated in a separated section in this study.

3. Abutment type

Abutment must have backwalls to keep the embankment from covering up the beam ends and to support possible approaches, for which compatibility between abutments and bridge approaches can be guaranteed. Generally, abutments can be classified into integral (movable) or non-integral (conventional or stub) types (Greimann, 1987). In order to characterize abutments more accurately, different types of abutments can be grouped into closed, perched, or spill-through. Closed abutments originate from the fact that tall walls are built to hold back the approach embankment, which results in higher lateral earth pressure. Closed

abutments must be constructed before the approach embankment, therefore there is a potential for closed abutment to settle more because it can be more difficult to bring large compaction equipment to compact the fill (Dupont and Allen, 2002). Perched abutments are usually construed on piles or shallow spread footings, so the embankment can be placed to the bottom elevation of the abutment. The embankment fill can be compacted to a good condition with an advantage that the lateral forces on perched abutments are the lowest of the other types, which leads to less lateral movement (Dupont and Allen, 2002). Spill-through abutments usually are placed on columns and must be constructed before the embankment. In this type, transmission of lateral force through columns is allowed. Embankment fill is also difficult to compact well since the abutments must be constructed before the embankment. Three typical bridges in different abutment types are illustrated in Figure 3.1, 3.2, and 3.3.



Figure 3.1 A typical full height closed or high abutment (bridge No. 094B00041N)



Figure 3.2 A typical perched abutment (bridge No. 056B00454R)



Figure 3.3 A typical spill-through abutment (bridge No. 056B00489N)

4. Embankment fill material and height

The deformation of the backfill material has been perceived and proven to be one of the crucial factors to cause bridge approach settlement (Hopkins, 1973; Wahls, 1990; Lenke, 2006; Helwany, 2007). Sam Helwany (2007) concluded that the causes of vertical and horizontal deformation of the backfill material result from volumetric changes in the soil, lack of compaction, post-construction consolidation settlement, and bearing capacity failure of the embankment soil. In

addition to deformation, lateral stability and shear strength of backfill material should also be considered as important factors in determining the overall stability of backfill. Lateral confining forces are usually considered significant for foundation soil, while on embankment backfills, the confinement effects receive much less attention (Wahls, 1990). In general, cohesive soils are more difficult to compact to their optimum moisture content and density when compared to coarser or granular fill materials (Hopkins, 1973). Some studies (Hopkins, 1973; Wahls, 1990) indicated that thick embankments tend to settle more than shallow ones. It is difficult to retrieve the fill material type based on the current storing system due to a large time span. For old bridges, there are no detailed instructions on what kind of materials were used in the design plan. For new bridges, embankments are usually constructed according to standard drawings (Std. Drwg. RGX-100; 105) for most bridges in Kentucky unless there is a note specifying that. Such a standardized fill composed of stabilized soil is inappropriate to be classified as a normal fill such as clay, silt, or sand. Consequently, the embankment height is merely considered as the proper variable that reflects the contribution of the embankment fill.

5. Foundation soil type (consistency) and thickness

Many studies (Hopkins, 1969; Wahls, 1990; Dupont and Allen, 2002) concluded that consolidation settlement of foundation soils contributed significantly to approach settlement. Foundation settlement typically results from a combination of dynamic traffic loads applied at the embankment surface and static load due to the weight of the embankment itself (Dupont and Allen, 2002). Although it is

easy to find the occurrence of settlement and determine its magnitude, the reasons for this problem are usually difficult to identify because of the variability of the engineering properties of foundation soils. In addition, it is difficult to access the foundation after construction because it is buried deep beneath the bridge approach/roadway surface (Wahls, 1990). More settlement would occur in cohesive soils after construction than non-cohesive soils because cohesive soils, such as soft or high plasticity clays, are more susceptible to soil plastic deformation, which can aggravate the approach settlement.

Foundation soil is usually a mixture of several types of soil, hence it is inappropriate to grossly categorize the foundation soil type as silt, clay, sand, or rock. However, the consistency of the foundation soil could be identified based on its engineering properties and composition of each type of soil. This research suggests that the consistency of the foundation soil could be classified as soft, stiff, very stiff, or hard, corresponding to different types of soil. The foundation soil thickness underneath the embankment is also considered as a variable to evaluate its effect, and it usually refers to the elevation difference between original ground and hard rock. The foundation soil depth is usually equal to zero for closed or perched abutments because they are usually built on hard soils/rock with stern borehole parameters. For pile-supported abutments, the foundation soil depth is normally equal to the length of the piles that are supported on hard rock.

6. District

When and how to initiate corrective measures when a differential approach settlement occurs vary from district to district. In addition, the current practice with regard to bridge maintenance is different between transportation districts. That is the main reason why the geographic regions are adopted as a major input factor.

7. Drainage

Poor drainage around the bridge abutments and under the approach pavements is a commonly perceived cause of bridge approach settlement. Many transportation agencies (such as Texas DOT, Virginia DOT, Iowa DOT, and Colorado DOT) documented the importance of the drainage and soil erosion. Improper, damaged, or blocked drainage systems can cause erosion in the abutment and embankment slope, which increases soil erosion and enlarges void formation (Hoyos, 2009). There are no uniform guidelines for the use, design, and construction of drainage systems nationwide. Therefore, it is tough to define drainage issues as numeric or categorical variables that are considered as inputs to develop a model to evaluate severity of approach settlement even though drainage has been perceived as one of the most important causing factors. Even if the drainage could be classified as a binary variable that whether the drainage design has been considered or not for an approach, it would make a futile effort of considering drainage as a factor in logistic regressions because almost every approach has adopted drainage design as required by KYTC. Another reasonable option defining drainage as a numerical variable is to assign different grades by rating different designs of

drainage, but this information is not always available in current storing system in KYTC.

3.2 Other Lurking Variables

1. Temperature cycle

Most bridges are characterized as integral or non-integral abutment bridges with the main difference in the connection between the bridge superstructure and the abutment. The non-integral bridges are usually supported on bearing connections that allow the superstructure to move longitudinally without transferring lateral loads to the abutment. Generally, battered piles are typically installed to accommodate for lateral loads on the abutment backwall and expansion joints are used as connections to tolerate the relative movement between the superstructure and the abutment. While for integral bridges, the superstructure is rigidly connected to the abutment in order to eliminate the use of bearing plates and forbid the relative movement. Bridge superstructure and approach usually expand and contract because of concrete thermal strain characteristics when they are exposed to temperature fluctuations. Both integral and non-integral bridges are vulnerable to differential settlements. However, the integral bridges are more susceptible to temperature fluctuations as the abutment backfill is more affected by temperature changes for the two reported problems (Arsoy et al, 1999):

- Development of a void near the abutment face
- Differential settlement between the bridge superstructure and approach embankment

This research does not consider this variable as an important variables due to the following two reasons:

- Most bridges used as research subject are non-integral bridges that are more resistant to temperature fluctuations
- All the bridges are subjected to the same temperature changes, therefore, it is meaningless to list this variable as an input for statistical analysis. But the influence from the temperature changes is still exist
- 2. Connection between the approach slab and the bridge

Several issues are involved in the connection between the approach slab and the bridge, including the approach slab dimensions, paving notch, sleeper beam, etc. Kentucky is one of the two states that consider the application of approach slab has little effect on the elimination/mitigation of differential settlement even though approach slabs are widely used nationwide. In addition, Hoppe (1999) conducted a survey (Table 3.1) and concluded that most of the bridges in Kentucky are non-integral and no doweled or tied connection between approach slab and bridge are installed. Therefore, whether approach slabs were used or not, it is more significant to consider the use of approach slabs as a model input instead of considering this input in more detail.

	Non-integ	ral Bridges	Integral	Bridges	Integral Abutments
State	Doweled or	No	Doweled or	No	Not Used
	Tied	Connection	Tied	Connection	1100 0 500
AL	×				×
AZ		×			
CA	×		×		
СТ		×			
DE		×			×
FL	×				×
GA		×		×	
IA	×			×	
ID	×		×		
IL	×		×		
IN		×	×		
KS	×		×		
KY		×			
LA	×				
MA	×			×	
MD					×
ME		×	×		
MN		×	×		
MO	×				
MS		×			×
MT		×			
ND				×	

Table 3.1 Connection between approach slab and bridge (Hoppe, 1999)

NJ		×			×
NH	×				
NV	×			×	
OH	×				
OK	×		×		
OR	×		×		
SC	×				
SD		×		×	
TN	×				
TX	×				×
VA		×	×		
VT	×				
WA	×		×		
WI		×			
WY	×		×		

3.3 Collection Method

Bridge length, width, year, and ADT could be easily retrieved from the KYTC online service "Bridge Data Miner" once a bridge is specified.

Once a bridge sample is determined, interviews with KYTC maintenance engineers would be conducted and bridge plans would be requested. Approach type for a bridge could be identified if the design plan for that bridge could be obtained and reviewed.

The abutment type can be identified explicitly from the site observation and verified from the design plan that are available in the design report at KYTC. Embankment height refers to elevation difference between the original ground level and the surface of backfill. The estimated value could be determined from the bridge elevation plans at KYTC.

Foundation soil information is contained in sounding plans that are included in the design plans for most bridges. For other bridges, foundation soil type can be grossly determined by reviewing a geotechnical report for a given project that provided by Kentucky Geological Survey (KGS). Foundation thickness underneath the embankment here measures from the bottom of the embankment to a dense or stiff deep soil stratum. It is difficult to distinguish the bond between soft and dense soil; therefore, precision of foundation soil thickness would be controlled within1~2 feet.

Drainage design has not been considered as a separate topic from the review of some old bridge plans. For newer bridges (less than 20 years), the drainage design varies from case to case. The proposed research will not consider this available as an input but discussion related to this issue will be involved in the section of the current practice that may effectively mitigate the bump problems.

The data base development was based on three sources: (I) basic bridge information from the KYTC online service "Bridge Data Miner", (II) interview of local bridge maintenance personnel, and (III) bridge inspection records and design plans maintained at the KYTC.

3.4 Model Output

Bridge approach settlement is the output of the anticipated model. The approach settlement here doesn't refer to the real settlement in the form of inches that the approach has experienced from the time it is opened to traffic. This study attempts to develop a model by using ordinal/nominal logistic regression based on a large-scale sample. No records regarding the real approach settlement are available in the current maintenance system. It is impractical to measure the real approach settlement of every bridge in the selected sample (basically 600 bridges). It is a wise way of addressing the output from the macro angle that classify the approach settlement severity as three levels: minimal, moderate, and severe.

One study conducted by Kentucky Transportation Center (KTC) (Dupont and Allen, 2002) indicated that the best practice to alleviate the bridge bump problems is to establish up-to-date maintenance activities, by scheduling periodic repair activities as well as occasional required maintenance. Maintenance techniques to rectify distressed/faulted approach generally include local patching, mud/slab jacking, asphalt overlay, and replacement (Wahls, 1990; Briaud, 1997; Dupont and Allen, 2002; Hoyos, 2009). The term "local patching" refers to the maintenance performed at a specified spots on the approach pavement. Mud/slab jacking is generally performed on bridges with approach slabs. It refers to a quick, convenient, and economical technique of raising a settled rigid approach to a desired elevation by pressure injecting cement grout or mud-cement mixtures (Hoyos, 2009). Asphalt overlay is adopted to improve the riding conditions of the entire roadway. Replacement of an approach is necessary where a highly deteriorated bridge approach has occurred due to the differential settlement. This technique is normally more expensive and time-consuming than other correction techniques. A good understanding of the mechanisms of these maintenance techniques is an essential prerequisite to define the severity of a bridge approach settlement.

There are two methods used to identify the severity of an approach settlement:

- One is determined by the frequency of maintenance or subjective judgment of district maintenance engineers based on their work experience. If more maintenance on correction approach settlement has been performed toward a bridge, the worse bump situation can be claimed. This method is used to judge the settlement levels of the first bridge sample from the survey.
- 2. After interviews with several KYTC maintenance engineers, there is no system or archive regarding maintenance history for a bridge even though some corrective actions were performed. However, there is an archive, named "Pontis", of most of bridges in Kentucky which contains all inspective activities and suggested mitigation methods for the emerged problems, including suggestions of solving approach settlement. From the inspection history, the maintenance actions could be assumed to have been occurred. It is important to note that inspection history is not equal to maintenance history, and the validity of using inspection history instead of maintenance will be verified by statistical analysis in the next chapter. Therefore, the other method of rating the severity of an approach settlement is originated from the inspection history "Pontis."

3.5 Rating Output Levels

No uniform system has been established for rating bridge approaches due to a complicated mechanism leading to differential settlement. Four rating systems as illustrated in chapter one are derived from micro level perspectives, while this paper rates the riding quality of an approach from macro level perspectives. The macro level methods here refer to techniques that determine the differential settlement scale by assessing the inspection history from "Pontis", basically an internal network server used

for storing inspection history of approaches of most bridges in Kentucky, or surveying the local bridge maintenance engineers . The "Pontis" database includes the last 6 to 8 years' inspection history of most bridges in Kentucky except for a few bridges in district four and district eight, and could be acquired from the KYTC. The other macro method is performed by electronic survey and district interviews, and the differential settlement scale of bridges from the survey is verified by local bridge engineers based on their work experience.

According to the macro level evaluation methods, the differential settlement scale could be classified as minimal, moderate, and severe, which corresponds to the approach performance status good, fair, and poor. Table 9 and Table 10 are given to summarize the similarities and differences between micro and macro methods in determining the differential settlement scale.

		Micro Method		
Rating	Description	Actual Settlement	IRI	
		(Inch)	(mm/m)	
Very	No Bump	0	0~4	
Good	No Dump	0	0	
Good	Slight Bump	~1 inch	5~8	
Fair	Moderate Bump – Readily Recognizable	~2 inch	9~12	
Poor	Significant Bump – Repair Needed	~3 inch	13~16	
Very Poor	Large Bump – Safety Hazard	> 3 inch	> 17	

Table 3.2 Micro methods in determining differential settlement scale

Table 3.3 Macro method in determining differential settlement scale

		Marco Met	hod
Rating Description		Inspection History (Pontis): Characteristics	Survey: Characteristics
Good	No bump or minimal/slight bump	No or less than 1.5 inches approach settlement was detected and no maintenance work is needed to correct differential settlement.	No maintenance work has been performed on fixing differential settlement since opening.
Fair	Moderate bump	Settlement ranging from 1.5 to 3 inches was detected and repair work including wedging repair, local patching, and mud jack may be needed. Problem may repeat in periodical inspection reports.	Differential settlement can cause a miner impact and 1 to 3 times of maintenance work have been performed on fixing it.

	Sottlement more than 2in shee	Differential settlement	
	Settlement more than 5inches	can cause a major	
Severe bump	was detected and problem lasts	impact and maintenance	
	for a long time. Transition have	work should be	
	to be resurfaced or approach		
	slabs need to be replaced.	performed every couple	
		of years.	
	Severe bump	Settlement more than 3inches was detected and problem lasts for a long time. Transition have to be resurfaced or approach slabs need to be replaced.	

3.6 Bridge Selection

3.6.1 Information from a Survey

An electronic questionnaire was created by "Surveygizmo" and distributed to managers of each transportation district. Then these managers sent this link to the specific bridge engineers that are responsible for bridge inspection or maintenance to identify and quantify differential settlement at bridge ends throughout each district. The purpose of this survey is to obtain information regarding the existence of bridges with "bump" issues, identify major causes of differential settlement at bridge ends, and evaluate the existing record keeping procedures regarding maintenance of "bump" issues. There are 35 bridge engineers participated in this survey, but only 18 engineers provided the completed and feasible information as requested. 131 bridges with different settlement severity were obtained. The distribution of these bridges is shown in Table 3.4. No bridges from District two and District eight are fed back. The bridge plans for only 87 bridges were able to be identified in the current bridge archive from KYTC due to the reasons that the other bridges are too new to be included in the current archive or some information for these bridges are missed. These bridges are composed of sample one for

analysis the relationship between approach settlement levels and its predictors in the next chapter.

District		Total No		
District	Minimal	Moderate	Severe	
1	2	2	2	6
3	0	0	3	3
4	0	2	3	5
5	0	9	1	10
6	6	23	26	55
7	0	4	5	9
9	0	3	3	6
10	2	2	2	6
11	10	6	9	25
12	0	0	6	6
	20	51	60	131

transportation district for sample one

 Table 3.4 Distribution of the bridges with different settlement levels from each

3.6.2 Information from the Transportation Cabinet

The primary source of data from the KYTC is the inspection history named "Pontis". It is basically an internal network server used for storing inspection history of approaches of most bridges in Kentucky. A simple random sample was created as sample two by randomly selecting 600 bridges from "Pontis". If bridges without inspection history were selected, these bridges would be deleted, and the selection process would be iterated to obtain 600 bridges with completed inspection history.

A simple random sampling was used to generate sample two, which means every bridge with the equal opportunity to be selected. Therefore, a transportation district which contains more bridges in the "Pontis" would has a higher probability that more bridges would be selected in the sample two. The method also guarantees that the sample two includes bridges from every transportation district.

District	Settlement Levels			Total No
District	Minimal	Moderate	Severe	10tal 110.
1	97	65	5	167
2	0	6	12	18
3	11	13	4	28
4	0	0	1	1
5	1	17	18	36
6	11	39	18	68
7	7	25	40	72
8	0	1	1	2
9	3	16	11	30
10	21	13	0	34
11	5	31	39	45
12	36	47	16	99
	192	273	135	600

Table 3.5 Distribution of the bridges with different settlement levels from eachtransportation district for sample two

3.7 Limitations of Data

Sampling is an important component of any piece of research because of the significant impact that it can have on the quality of your results/findings. The samples used in this research would be studied to obtained conclusions that stands for the entire population.

Hence the accuracy of the conclusions is usually dependent upon the reliability of the data. This section mainly discusses some of the limitations of the data for sample one and sample two, respectively.

1. Limitation of the data for sample one

The biggest limitation of the data for sample one is the sample size. Even 131 bridges were collected for sample one, but only 87 with completed information can be used for analysis. Our research team had tried to contact as many bridge maintenance engineers as we can to obtain a sample with sufficient individuals. For logistic regression which discussed in the next chapter, a model constructed by a small sample size may lead to unreliable conclusions.

Several responders provided the same bridges with different settlement levels. This phenomenon can be explained by two aspects. First, the maintenance bridge engineers evaluate the settlement level for a bridge based on his or her work experience. The work experience for each respondent is different. In many cases, the maintenance engineer had been working for a particular district for a length of time that was much shorter than the age of the approach. Some engineers may work more than several decades in a district, while some engineers may just start their work life. If they judge the settlement level for a bridge based on their work experience, they may conclude differently. In this scenario, a higher settlement level would be adopted for a bridge given different levels by different respondents. For example, moderate and minimal settlement levels were given for the same bridge, moderate would be adopted for this bridge. Second, different rating criterion may be applied by different respondents. Some bridge maintenance engineers use the number of maintenance times to evaluate the

settlement levels, while some bridge maintenance engineers use the observed settlement in inches to evaluate the settlement levels. Different evaluation criterion may conclude different results.

Generally, the bridges with the worst settlement situations may impress the responders most. In this case, sample one may include more bridges with severe settlement than other settlement levels. The observed results verified this assumption. There are 60 bridges with severe settlement while 20 approaches in minimal and 51 approaches in moderate. In this sense, sample one may lead to selection bias.

2. Limitation of the data for sample two

A simple random sample is a subset of individuals chosen from a larger population. Each individual is chosen randomly and entirely by chance, such that each individual has the same probability of being chosen at any stage during the sampling process. It was envisioned that no one type or factor had significant dominance on the selection process. A simple random sample is an unbiased surveying technique. Based on the above considerations, the random sampling method was used to generate sample two. In this sense, sample two would not lead to selection bias.

The system "Ponits" only provides the inspection history for most of the bridges in Kentucky in the last ten years. The current situation of the settlement levels could be identified without giving earlier maintenance actives. Even if the settlement level for a bridge could be summarized by using last years' maintenance history, there is still a chance that this bridge was rebuilt or approach slabs were replaced more than ten years

ago. In this case, the current settlement level for an approach cannot reflect the true settlement level.

In the inspection history "Pontis", there are exact maintenance times and what kind of maintenance activities were undertaken for some bridges. While there are observed true settlement in inches were measured for some bridges. It is not a problem to evaluate the settlement level for an approach solely based on one evaluation criteria, maintenance times or observed settlement, shown in Table 3.3. For some bridges, the "Pontis" not only provides maintenance times but also observed accumulative settlement. There is a chance that two different settlement levels for an approach may be reached based on two evaluation criterion. In this situation, the higher settlement level would be selected for that bridge.

4 DATA ANALYSES

The major goal of this study is to estimate the probability of occurrence of each of the three settlement levels as well as to estimate the odds of severity choice as a function of the covariates and to express the results in terms of odds ratios for severity choice given bridge characteristics. The independent variables of interest both consist of count data and categorical (ordinal and nominal) variables. The outcome (response) variable is ternary: minimal, moderate, or severe, and it is assumed as ordinal under the assumption that the levels of approach settlement have a natural ordering (low to high), but the distances between adjacent levels are not consistent (see Table 3.3).

Logistic regression is a type of a probabilistic statistical classification model that is used for predicting the outcome of a categorical dependent variable based on one or more predictors or features. Two methods are usually used to conduct logistic regression analyses. The ordinal regression procedure is usually used to build models, generate predictions, and evaluate the importance of various predictor variables in cases where the dependent variable is ordinal in nature. Multinomial logistic regression is used to model nominal outcome variables, in which the log odds of the outcomes are modeled as a linear combination of the predictor variables. Because it is uncertain to treat settlement severities as a true ordering variable, ordinal logistic regression will be carried out at first, and then multinomial logistic regression are the same across response categories is violated.

A code sheet for the variables that are included in data analyses for identifying the relationship between each parameter (all parameters) and dependent variable is given in Table 4.1.

Variable	Description	Codes/Values	Name
1	Geographical location	District Number 1=District 1 2=District 2 12=District 12	DISTRICT
2	Age of bridge approaches	Years	AGE
3	Bridge length	Ft.	LENGTH
4	Bridge width	Ft.	WIDTH
5	Average daily traffic	Number/day	ADT
6	Abutment type	1=closed 2=spill-through 3=perched	ABUT
7	Approach type	1=flexible 2=rigid	APPT
8	Embankment height	Ft.	EH
9	Foundation soil depth	Ft.	FSD
10	Foundation soil consistency	1=soft 2-stiff 3=very stiff 4=hard	FSC
11	Bridge approach settlement	1=minimal 2=moderate 3=severe	SEVERITY

 Table 4.1 Code sheet for the variables in samples

4.1 Approach Age

4.1.1 Sample One

This section is interested in the approach age that influence whether an approach is experiencing minimal settlement or severe settlement. It is helpful to start with exploring the relationship between approach age and the settlement severity for sample one. Had the outcome variable been continuous rather than ternary (polytomous), a scatterplot of the outcome versus the independent variables was formed. This scatterplot may be used to provide an impression of the nature and strength of any relationship between the settlement severity and the causative variables. A scatterplot of the data in sample one is given in Figure 4.1. In this scatterplot, all points fall on one of three parallel lines representing the settlement levels. There is some tendency for the bridges with moderate or severe settlement to be younger than those with minimal settlement. While this plot does depict the polytomous nature of the settlement levels quite clearly, it is not able to provide a clear picture of the nature of the relationship between AGE and SEVERITY.




The main problem with this scatterplot is that the variability in SEVERITY at all ages is large, and it is difficult to see any functional relationship between AGE and SEVERITY. An effective way of solving this problem, while still maintaining the structure of the relationship between the dependent and the independent variable, is to create intervals for the independent variables by removing some variation and compute the mean of the response within each group. This strategy is used to group the independent variable AGE into four categories (AGEG) defined in Table 4.3. The percentage of SEVERITY with minimal and severe are also computed. Figure 4.2 and Figure 4.3 present two plots of the percent of approach with minimal or severe settlement versus the midpoint of each age interval. By examining Figure 4.2, it shows that as approach age increases within 0~30years, the proportion of approaches with minimal settlement decrease, and then as approach age increase within 30~60 years, the proportion of approaches with minimal settlement increases. By examining Figure 4.3, the proportion of approaches with severe settlement increases as age increases during the stage of $0\sim30$ years. Then, the proportion of approaches with severe settlement decreases as age increases within 30~45 years, and finally the proportion of approaches with severe settlement increases as age increases after 45 years. The variation of the proportion of approaches with minimal settlement shows an almost reverse tendency with the variation of the proportion of approaches with severe settlement. This strategy above provides, to some extent, considerable insight into the relationship between AGE and SEVERITY. However, the functional form for this relationship need to be analyzed by logistic regression.

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Age group		Severity			Me	an
(year)	Minimal	Moderate	Severe	10101	Minimal	Severe
0~15	3	13	16	32	0.094	0.500
16~30	1	4	9	14	0.071	0.643
31~45	3	9	3	15	0.200	0.200
Above 45	7	10	9	26	0.269	0.346
	14	36	37	87		

Table 4.2 Sample One: Frequency table of age group (AGEG) by SEVERITY



Figure 4.2 Sample One: Plot of the percentage of approaches with minimal

SEVERITY in each age group



Figure 4.3 Sample One: Plot of the percentage of approaches with severe SEVERITY in each age group

Many statistical packages are able to conduct logistic regression analyses. Statistical Package for the Social Sciences (SPSS) is employed to explore the relationship between AGE and SEVERITY as well as other relationships in the following logistic regressions. Since the outcome is an ordinal categorical variable with three levels, the program of ordinal logistic regression is adopted at first. Below the ordinal logistic regression command is used to run a model predicting the outcome variable SEVERITY, using AGE. The output is shown in Table 4.3 ~ Table 4.5, each of which is discussed below.

Table 4.3 Sample One: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	129.841			
Final	125.172	4.668	1	.031

between AGE and SEVERITY

- Model: This indicates the parameters of the model for which the model fit is calculated. "Intercept Only" describes a model that does not control for any independent variables and simply fits an intercept to predict the outcome variable. "Final" describes a model that includes the specified independent variables and has been arrived at through an iterative process that maximizes the log likelihood of the outcomes seen in the outcome variable. By including the independent variables and maximizing the log likelihood of the outcomes seen in the data, the "Final" model should improve upon the "Intercept Only" model. This can be seen in the differences in the -2(Log Likelihood) values associated with the models.
- -2(Log Likelihood): This is the product of -2 and the log likelihoods of the null model and fitted "final" model. The likelihood of the model is used to test of whether all independent variables' regression coefficients in the model are simultaneously zero and in tests of nested models.
- Chi-Square: This is the Likelihood Ratio (LR) Chi-Square test that at least one of the predictors' regression coefficient is not equal to zero in the model.

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- df: This indicates the degrees of freedom of the Chi-Square distribution used to test the LR Chi-Square statistic and is defined by the number of predictors in the model.
- Sig.: This is the probability of getting a LR test statistic as extreme as, or more so, than the observed under the null hypothesis; the null hypothesis is that all of the regression coefficients in the model are equal to zero.

The p-value for this regression model is 0.031 that is smaller than a specified alpha level (if 0.05 is set in this study). This would lead to conclude that this model fits better than an empty model (i.e., model with no independent variables). In other words, the relationship between AGE and SEVERITY can be described by this model.

 Table 4.4 Sample One: Parameter estimates of ordinal logistic regression between

		Estimate	Std. Wald df		df Sig	95% Confidence Interval		
		Lotinute	Error	vv ard	uı	515.	Lower Bound	Upper Bound
	[SEVERITY	-2.349	454	26.766	1	.000	-3 239	-1.459
Threshold	= 1.00]	2.5 19	1101	20.700	-	.000	0.207	11103
	[SEVERITY	- 312	363	739	1	.390	-1.024	400
	= 2.00]	.012	1000		-	.070	1.021	
Location	AGE	021	.010	4.661	1	.031	040	002

AGE and SEVERITY

 SEVERITY=1.00: This is the estimated cutpoint on the latent variable used to differentiate low SEVERITY from middle and high SEVERITY when values of the independent variables are evaluated at zero. Subjects that had a value of -2.349 or less on the underlying latent variable (SEVERITY) that gave rise to SEVERITY would be classified as low SEVERITY given the approaches' age were zero.

- SEVERITY=2.00: This is the estimated cutpoint on the latent variable used to differentiate low and middle SEVERITY from high severity when values of the independent variables are evaluated at zero. Subjects that had a value of -0.312 or greater on the underlying latent variable that gave rise to SEVERITY would be classied as high SEVERITY given the approaches' age were zero. Subjects that had a value between -2.349 and -0.312 on the underlying latent variable would be classified as middle SEVERITY.
- Estimate: These are the ordered log-odds (logit) regression coefficients. Standard interpretation of the ordered logit coefficient is that for a one unit increase in the predictor, the response variable level is expected to change by its respective regression coefficient in the ordered log-odds scale while the other variables in the model are held constant. Interpretation of the ordered logit estimates is not dependent on the ancillary parameters; the ancillary parameters are used to differentiate the adjacent levels of the response variable. However, since the ordered logit model estimates one equation over all levels of the outcome variable, a concern is whether our one-equation model is valid or a more flexible model is required. The odds ratios of the predictors can be calculated by exponentiating the estimate.
- Std. Error: These are the standard errors of the individual regression coefficients.
- Wald: This is the Wald chi-square test that tests the null hypothesis that the estimate equals zero.

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• 95% Confidence Interval: This is the Confidence Interval (CI) for an individual regression coefficient given the other independent variables are in the model

In this model, if an approach were to increase AGE by one year, the ordered log-odds of being in a higher SEVERITY (i.e., from minimal to moderate, or from moderate to severe) category would decrease by 0.021 while the other variables in the model are held constant (only one dependent variable is used here). The Wald test statistic for the independent variable is 4.661 with an associated p-value of 0.031. If the alpha level 0.05 is selected, the null hypothesis would be rejected and conclude that the regression coefficient for AGE has been found to be statistically significant in estimating SEVERITY given other variables, although none others in this model, are in the model. In other words, AGE is found statistically associated with SEVERITY. For ordinal logistic regression, the null hypothesis states that the location parameters (slope coefficients) are the same across response categories. The SPSS output shows that this null hypothesis cannot be rejected due to a high significance level 0.342 as shown in table of test of parallel lines.

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	125.172			
General	124.269	.903	1	.342

Table 4.5 Sample One: Test of parallel lines of ordinal logistic regression between

AGE and SEVERITY

• General: This table is the output that tests the proportional odds assumption. This is commonly referred to as the test of parallel lines because the null hypothesis states that the slope coefficients in the model are the same across response categories (and lines of the same slope are parallel). Since the ordered logit model estimates one equation over all levels of the response variables, the test for proportional odds tests whether this one-equation model is valid. If a null hypothesis was rejected based on the significance of the Chi-Square statistic, it would conclude that ordered logit coefficients are not equal across the levels of the outcome, and a less restrictive model (i.e., multinomial logit model) may fit better. If the null hypothesis was failed to be rejected, the assumption would hold. The significance of Chi-Square statistic for this model is 0.342>0.1, which implies that the ordinal logistic regression is appropriate for obtaining the relationship between AGE and SEVERITY.

Because this model is found statistically significant. The response Y in this study has three levels which are represented by 1, 2, and 3, and the associated probabilities are π_1 , π_2 , and π_3 . The relationship between AGE and SEVERITY for sample one can be described by the following equations:

$$Logit \frac{\pi_1}{1 - \pi_1} = Logit \frac{\pi_1}{\pi_2 + \pi_3} = -2.349 - 0.021AGE$$
(4.1)

$$Logit \frac{\pi_1 + \pi_2}{1 - (\pi_1 + \pi_2)} = Logit \frac{\pi_1 + \pi_2}{\pi_3} = -0.312 - 0.021AGE$$
(4.2)

Therefore,

$$\pi_1 = \frac{\exp(-2.349 - 0.021AGE)}{1 + \exp(-2.349 - 0.021AGE)}$$
(4.3)

$$\pi_2 = \frac{\exp(-2.349 - 0.021AGE)}{1 + \exp(-2.349 - 0.021AGE)} - \pi_1 \tag{4.4}$$

$$\pi_3 = 1 - \pi_1 - \pi_2 \tag{4.5}$$

By using equations from 4.1 to 4.5, it is able to compute the probability that each settlement category may occur solely based on the independent variable AGE.

4.1.2 Sample Two

Had the dependent variable been continuous rather than ternary, a scatterplot of the SEVERITY versus the AGE was created for sample two to provide a descriptive impression of the nature and strength of any relationship between the outcome and the independent variable. The same as sample one, no clear relationship could be revealed by this scatterplot.



Figure 4.4 Sample Two: Scatterplot of approach settlement levels by approach age

Then the data in the sample two was divided into four age groups to obtain the relationship between the percentage of SEVERITY with minimal (severe) and AGE. The result is shown in Table 4.6. Figure 4.5 shows that the proportion of approaches with minimal settlement increases as approach age increases within 30 years, while the proportion of approaches with minimal settlement decreases as approach age increases after 30 years. Figure 4.6 shows that the proportion of approaches with severe settlement varies slightly among different age groups. The changing tendency of the percentage of approaches in sample two with minimal settlement shows a contradictory trend with the sample one.

Age group		Severity		Total	Me	ean
(year)	Minimal	Moderate	Severe	Total	Minimal	Severe
0~15	13	41	15	69	0.188	0.217
16~30	65	49	31	145	0.448	0.214
31~45	45	47	29	121	0.372	0.240
Above 45	69	136	60	265	0.260	0.226
	192	273	135	600		

Table 4.6 Sample Two: Frequency table of age group (AGEG) by SEVERITY



Figure 4.5 Sample One: Plot of the percentage of approaches with minimal

SEVERITY in each age group



Figure 4.6 Sample Two: Plot of the percentage of approaches with severe SEVERITY in each age group

An ordinal regression was also carried out to obtain the functional relationship between the settlement severity and the approach age for sample two. The p-value (Sig.) from the output of model fitting information is larger than 0.05 and indicates that this model is not better than a null model without any predictors. For sample two, if an approach were to increase AGE by one year, the ordered log-odds of being in a higher SEVERITY category would increase by 0.006 while the other variables in the model are held constant. The Wald test statistic for the variable AGE is 2.221 with an associated p-value of 0.136. If the alpha level 0.05 is selected, the null hypothesis cannot be rejected. In other words, the approach age is not statistically significant associated with settlement levels. The analysis of test of parallel lines indicates that the proportional odds assumption is not violated and the method of ordinal regression for identifying the relationship between the settlement severity and the approach age is applicable. If the proportional odds assumption was violated, a less restrictive model, such as the multinomial logistic regression, would be used. Since this model cannot fit the relationship between AGE and SEVERITY well for sample two, no equations would be given to describe their functional relationship.

 Table 4.7 Sample Two: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	496.710			
Final	494.397	2.313	1	.128

between AGE and SEVERITY

Note: Link function: Logit

Table 4.8 Sample Two: Parameter estimates of ordinal logistic regression between

AGE and SEVERITY

							95% Confidence Interval	
		Estimate	Std.	Wald	df	Sig.		
			Error			Lower U		Upper
							Bound	Bound
	[SEVERITY	- 524	176	8 910	1	003	- 868	- 180
Threshold	= 1.00]	524	.170	0.710	1	.005	000	100
1 mesnore	[SEVERITY	1 472	106	62 806	1	000	1 109	1 027
	= 2.00]	1.475	.180	02.800	1	.000	1.108	1.857
Location	AGE	.006	.004	2.221	1	.136	002	.013

Table 4.9 Sample Two: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	494.397			
General	492.923	1.474	1	.225

AGE and SEVERITY

Note: The null hypothesis states that the location parameters (slope coefficients) are the same across response categories.

4.1.3 Conclusions

The ordinal regression is applicable to explore the relationship between the settlement severity and the approach age. The result of sample one is not exactly the same with sample two. Sample one shows that AGE is statistically significant while sample two is not. Furthermore, the changing tendency of proportion (mean) of approaches with minimal settlement of the sample one is different with sample two. This divergence could be explained from several aspects: (1) two samples were based on different evaluation criterions of settlement severity with different sample size, (2) the outcome of the sample one was determined by local bridge engineers depending on their work experience that may be varied by person to person, and (3) the predictor variable AGE was classified as continuous variable for both ordinal logistic regressions, however, 55.3% of cells (i.e., dependent variable levels by observed combinations of predictor variable values) with zero frequencies for sample one, which may lead to unstable model for sample one.

Most types of logistic regression, using maximum likelihood estimates, require sufficient sample size. How big is big is a topic of some debate. But a check for empty or small cells by doing a crosstab between categorical independent variables and the outcome variable is needed. If a cell has very few cases, the model may become unstable or it might not run at all. In this sense, the output of sample two has a higher reliability than model of sample one while the sample two concludes that AGE is not significantly associated with SEVERITY. A comprehensive analysis including all predictor variables is absolutely needed for both samples to obtain a more complete answer for the relationship between the settlement severity and the approach age.

4.2 Bridge Length and Width

No previous studies had listed bridge length or width as an important factor that may affect the bridge end settlement between the abutment and the roadway. This study collected the bridge length and width as the basic information as well as other important factors mentioned in other literatures. The variables LENGTH and WIDTH were treated the same as AGE. A descriptive relationship was depicted firstly, and then the changing tendency of proportion (mean) of approaches with minimal or severe settlement was illustrated. Finally, statistical package SPSS was used to obtain any functional relationship between the bridge length (width) and the settlement severity.

4.2.1 Sample One

Scatterplots of the outcome versus the bridge length and width are given in Figure 4.7 and Figure 4.8, respectively. The approaches with bridge length between 100 and 300 feet seem to have been experiencing a higher severity level compared to the approaches with bridge length longer than 400 feet. But no distinct relationship between the approach settlement and the bridge length (width) could be perceived sorely based on these scatterplots. In order to further explore the relationship between LENGTH and SEVERITY, length group (LENGTHG) was created by dividing length into several groups shown in Table 4.10. Table 4.10 contains, for each length group, the frequency of occurrence of each settlement severity, as well as the presence of the percent with Minimal or Severe. Figure 4.9 presents a plot of the percent of approaches with minimal settlement versus the midpoint of each length interval. It shows that the approaches with bridge length between 300 and 400 feet have the highest proportion in minimal settlement while the approaches with bridge length between 200 and 300 feet have the lowest proportion in minimal settlement. Similarly, the percent of approaches with severe settlement versus the midpoint of each length interval is given in Figure 4.10. The highest proportion of approaches in severe settlement falls in the range between 0 and 100 feet, while the lowest proportion of approaches in severe settlement lies in the range between 100 and 200 feet.

 Table 4.10 Sample One: Frequency table of length group (LENGTHG) by

 SEVERITY

Length		Severity			Mean		
group (feet)	Minimal	Moderate	Severe	Total	Minimal	Severe	
0~100	2	2	5	9	0.222	0.556	
101~200	2	8	5	15	0.133	0.333	
201~300	4	15	14	33	0.121	0.424	
301~400	4	5	7	16	0.250	0.438	
Above 400	2	6	6	14	0.143	0.429	
Total	14	36	37	87			



Figure 4.7 Sample One: Scatterplot of approach settlement levels by bridge length



Figure 4.8 Sample One: Scatterplot of approach settlement levels by bridge width



Figure 4.9 Sample One: Plot of the percentage of approaches with minimal

SEVERITY in each length group



Figure 4.10 Sample One: Plot of the percentage of approaches with severe

SEVERITY in each length group

The frequency table of width group (WIDTHG) by SEVERITY is shown in Table 4.11. From Figure 4.11 and 4.12, it can be seen that both the proportions of approaches with minimal severity and severe severity increase as width increases before 40 feet and then decrease as width increases after 40 feet.

Width		Severity			Mean		
Group	Minimal	Moderate	Severe	Total	Minimal	Severe	
(feet)	1,1111111111	moderate	Severe				
0~20	2	8	6	16	0.125	0.375	
21~40	10	16	27	53	0.189	0.509	
41~60	2	10	4	16	0.125	0.250	
Above 60	0	2	0	2	0	0	
Total	14	36	37	87			

 Table 4.11 Sample One: Frequency table of width group (WIDTHG) by SEVERITY



Figure 4.11 Sample One: Plot of the percentage of approaches with minimal

SEVERITY in each width group



Figure 4.12 Sample One: Plot of the percentage of approaches with severe

SEVERITY in each width group

Then the ordinal regressions were conducted to identify the functional relationship between the bridge length (width) and the settlement severity. The results are shown in Table 4.12 ~ Table 4.17. The p-value for the model of the relationship between LENGTH and SEVERITY is 0.630, which implies that this model is not better than a null model without any predictors and cannot fit the relationship well. The LENGTH is not statistically significant related with SEVERITY as the regression coefficient of length is 0.597. Likewise, the relationship between WIDTH and SEVERITY is also not statistically significant due to a high p-value 0.396. By examining the output of test of parallel lines for both the relationships between LENGTH and SEVERITY and between WIDTH and SEVERITY, the method of ordinal regression is applicable because the null hypothesis states that the slope coefficients in the model are the same across response categories cannot be rejected. Because these two models can not reflect the relationships in this section very well, the expressions of these two models in equations are not given here.

	-2 Log			
Model	Likelihood	Chi-Square	df	Sig.
Intercept Only	173.194			
Final	173.563	0.231	1	.630

Table 4.12 Sample One: Model fitting information of ordinal logistic regression between LENGTH and SEVERITY

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Table 4.13 Sample One: Parameter estimates of ordinal logistic regression between

			Std.			95% Confidence Interval		
		Estimate	Error	Wald	df	Sig.	Louvon Dound	Linnan Daund
			EII0I				Lower Bound	Оррег Боина
	[SEVERITY							
	1 001	-1.807	.420	18.461	1	.000	-2.631	983
Threshold	= 1.00]							
Theone	[SEVERITY							
		.150	.362	.173	1	.678	558	.859
	= 2.00]							
Location	LENGTH	001	.001	.280	1	.597	002	.001

Length and SEVERITY

Table 4.14 Sample One: Test of parallel lines of ordinal logistic regression between

LENGTH and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	173.563			
General	172.842	.721	1	.396

Table 4.15 Sample One: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	90.944			
Final	90.329	.615	1	.433

between WIDTH and SEVERITY

Table 4.16 Sample One: Parameter estimates of ordinal logistic regression between

			Std.	XX 7 1 1	11	Sig	95% Confidence Interval	
		Estimate	Error	wald	đī	S1g.	Lower Bound	Upper Bound
								11
	[SEVERITY	2.021		10 100	1	000	0.155	077
	- 1 001	-2.021	.579	12.199	1	.000	-3.155	877
Threshold	- 1.00]							
	[SEVERITY							
	-2.001	057	.517	.012	1	.913	-1.091	.976
	- 2.00]							
Location	WIDTH	011	.015	.534	1	.465	041	0.019

WIDTH and SEVERITY

Table 4.17 Sample One: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	90.329			
General	88.596	1.733	1	.188

WIDTH and SEVERITY

4.2.2 Sample Two

The analysis process for sample one was iterated in this section to analyze the relationship between the bridge length (width) and the settlement severity for sample two. The proportion of approaches with minimal settlement versus the midpoint of each length interval of sample two shows similar changing trend with sample one: the proportion of severity in minimal increases as the length increases at first, then decreases as the length increases in the middle, and then increases as the length increases after 400 feet. While the proportion of approaches with severe settlement changes within a small degree as the length varies.

The percentage of approaches with minimal SEVERITY in each width group of sample two increases as the bridge width increases if the bridge width less than 20 feet, and then decreases if the bridge width continues to increase. This changing trend is also similar with sample one.

Table 4.18 Sample Two: Frequency table of length group (LENGTHG) by

Length		Severity			Mean	
group (feet)	Minimal	Moderate	Severe	Total	Minimal	Severe
0~100	69	59	32	160	0.431	0.200
101~200	54	100	41	195	0.277	0.210
201~300	39	61	32	132	0.295	0.242
301~400	12	23	20	55	0.218	0.364
Above 400	18	30	10	58	0.310	0.172
	192	273	135	600		

SEVERITY

Table 4.19 Sample Two: Frequency table of width group (WIDTHG) by

SEVERITY

Width		Severity			Mean	
Group (feet)	Minimal	Moderate	Severe	Total	Minimal	Severe
0~20	11	24	13	48	0.229	0.271
21~40	141	177	86	404	0.349	0.213
41~60	30	41	19	90	0.333	0.211
Above 60	10	31	17	58	0.172	0.293
Total	192	273	135	600		



Figure 4.13 Sample Two: Plot of the percentage of approaches with minimal

SEVERITY in each length group



Figure 4.14 Sample Two: Plot of the percentage of approaches with severe

SEVERITY in each length group



Figure 4.15 Sample Two: Plot of the percentage of approaches with minimal

SEVERITY in each width group



Figure 4.16 Sample Two: Plot of the percentage of approaches with severe

SEVERITY in each width group

The following is the output from the statistical package SPSS. Table 4.20 shows that the model between LENGTH and SEVERITY is not statistically significant and cannot reflect the relationship well. However, the p-value of the model between WIDTH and SEVERITY is 0.02 that is smaller than 0.05, which indicates this model can fit the relationship between the bridge with and the settlement severity well. The regression coefficient 0.003 reveals that there is an association between WIDTH and SEVERITY for sample two. This relationship can be expressed in the following equations:

$$Logit \frac{\pi_1}{1 - \pi_1} = Logit \frac{\pi_1}{\pi_2 + \pi_3} = -0.355 + 0.011 WIDTH$$
(4.6)

$$Logit \frac{\pi_1 + \pi_2}{1 - (\pi_1 + \pi_2)} = Logit \frac{\pi_1 + \pi_2}{\pi_3} = 1.661 + 0.011 WIDTH$$
(4.7)

The probability relationship between different settlement levels are shown in equation 4.3, 4.4, and 4.5. By combining the equations 4.6 and 4.7, the probability that each settlement category may occur could be computed.

Table 4.20 Sample Two: Model fitting information of ordinal logistic regression

between LENGTH and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	893.936			
Final	891.874	2.061	1	.151

Table 4.21 Sample Two: Parameter estimates of ordinal logistic regression between

							95% Co	nfidence
			Std. Estimate		df	Sig.	Interval	
			Error			U	Lower	Upper
							Bound	Bound
	[SEVERITY	660	111	35 107	1	000	878	442
Threshold	= 1.00]	000	.111	55.107	1	.000	070	442
	[SEVERITY	1 226	102	110 742	1	000	1.006	1 577
	= 2.00]	1.330	.125	116.745	1	.000	1.090	1.377
Location	LENGTH	.000	.000	1.760	1	.185	.000	.001
Threshold	[SEVERITY = 1.00] [SEVERITY = 2.00] LENGTH	660 1.336 .000	.111 .123 .000	35.107 118.743 1.760	1	.000 .000 .185	Bound 878 1.096 .000	442 1.577

LENGTH and SEVERITY

Table 4.22 Sample 7	Fwo: Test of na	rallel lines of a	ordinal logistic	regression between
Table 4.22 Sample .	I wo. I cot of pa	i anci mico oi v	or unnar rogistic	regression between

LENGTH and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	891.874			
General	888.733	3.141	1	.076

Table 4.23 Sample Two: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	343.809			
Final	334.022	9.787	1	.002

between WIDTH and SEVERITY

Table 4.24 Sample Two: Parameter estimates of ordinal logistic regression between

WIDTH and SEVERITY

							95% Co	nfidence
			Std.	Wald	df	Sig.	Inte	rval
		~ ~ ~ ~ ~ ~ ~ ~ ~	Error		•	~-8	Lower	Upper
							Bound	Bound
	[SEVERITY	355	.157	5.135	1	.023	662	048
 Threshold	= 1.00]							
	[SEVERITY	1 661	172	02 252	1	000	1 224	1 008
	= 2.00]	1.001	.1/2	95.552	1	.000	1.324	1.990
Location	WIDTH	.011	.004	9.025	1	.003	.004	.018

Table 4.25 Sample Two: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.	
Null Hypothesis	334.022				
General	331.729	2.293	1	.130	

WIDTH and SEVERITY

4.2.3 Conclusions

The ordinal regression results show that there is not significant relationship between the bridge length and the settlement severity both for sample one and sample two. The SPSS output shows that there is an association between WIDTH and SEVERITY for sample two, while no relationship exists for sample one. The statistical model of sample one cannot reflect the relationship between the bridge width and the settlement severity very well due to a little bit high model p-value 0.151>0.05. But a significant relationship between WIDTH and SEVERITY is found if a sample has sufficient data. The functional relationship for sample two shows that for one unit increase in WIDTH, a 0.011 increase in the ordered log odds of being in a higher settlement level given all of the other variables in the model are held constant. This conclusion should be compare to the comprehensive model which is illustrated in the last section of this chapter.

4.3 Average Daily Traffic

The opinion on the relationship between the traffic volume and approach settlement is debatable. High volume traffic has been found to be a compelling reason for the formation of approach settlement (Wong and Small, 1994). On the one hand, Lenke (2006) concluded that bump severity was found to increase with vehicle velocity, vehicle weight, especially heavy truck traffic, and ADT. On the other hand, Bakeer (2005) noted that speed limit and traffic volume almost have no effect on the performance of bridge approaches. The relationship between ADT and Severity would be identified in this section.

4.3.1 Sample One

It is not appropriate to process ADT as AGE because the variability in ADT is very considerable from several decades to hundreds of thousands. Therefore, no scatterplots or proportion changing tendency of approaches with different levels in different ADT were described here. The output from SPSS was used for inference the relationship between ADT and SEVERITY.

 Table 4.26 Sample One: Model fitting information of ordinal logistic regression

 between ADT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	170.786			
Final	170.221	.565	1	.452

			Std.			~ .	95% Confidence Interval	
		Estimate		Wald	df	Sig.		1
			Error				Lower Bound	Upper Bound
	[SEVERITY							
		-1.764	.333	28.060	1	.000	-2.417	-1.111
	= 1.00]							
Threshold								
	[SEVERITY							
		199	.258	.591	1	.442	-0.308	.705
	= 2.00]							
Location	ADT	0.000	.000	.446	1	.504	-3.829E-5	1.833E-5

ADT and SEVERITY

Table 4.28 Sample One: Test of parallel lines of ordinal logistic regression between

ADT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	170.221			
General	167.055	.3.166	1	.075

Table 4.26 shows that the p-value of the model 0.452 lead to conclude that this model is not different with a null model. The regression coefficient for ADT is 0.504, which indicates ADT is not significantly related with SEVERITY. From Table 4.28, the null hypothesis that the slope coefficients in the model are the same across response

categories is violated if an alpha value 0.05 is specified. A less restrictive model (multinomial logistic regression) was used to verify the output from ordinal regression.

Table 4.29 Sample One: Model fitting information of multinomial logistic regression between ADT and SEVERITY

Model	Model Fitting Criteria	Likelihood Ratio Tests			
	-2 Log Likelihood	Chi-Square	df	Sig.	
Intercept Only	170.786				
Final	166.511	4.275	2	.118	

Table 4.30 Sample One: Parameter estimates of multinomial logistic regression

between ADT and SEVERITY

		В	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence	
SEVERITY	ERITY							Interval fo	or Exp(B)
								Lower	Upper
								Bound	Bound
1.00	Intercept	970	.404	5.764	1	.016			
	ADT	.000	.000	.000	1	.996	1.000	1.000	1.000
2.00	Intercept	373	.305	1.500	1	.221			
	ADT	.000	.000	2.706	1	.100	1.000	1.000	1.000

Note: The reference category is 3.00

- B: These are the estimated multinomial logistic regression coefficients for the models. An important feature of the multinomial logit model is that it estimates k-1 models, where k is the number of levels of the outcome variable. In this instance, SPSS is treating the Severe as the referent group and therefore estimated a model for Minimal relative to Severe and a model for Moderate relative to Severe.
- Exp (B): These are the odds ratios for the predictors. They are the exponentiation of the coefficients. The odds ratio of a coefficient indicates how the risk of the outcome falling in the comparison group compared to the risk of the outcome falling in the referent group changes with the variable in question. An odds ratio > 1 indicates that the risk of the outcome falling in the comparison group relative to the risk of the outcome falling in the referent group increases as the variable increases. In other words, the comparison outcome is more likely to occur. An odds ratio < 1 indicates that the risk of the outcome falling in the referent group decreases as the variable increases.

Therefore, since the parameter estimates are relative to the referent group, the standard interpretation of the multinomial logistic regression is that for a unit change in the predictor variable, the logit of outcome SEVERITY relative to the referent group is expected to change by its respective parameter estimate (which is in log-odds units) given the variables in the model are held constant. In this model, (1) Minimal relative to Severe: for a one unit increase in ADT for Minimal relative to Severe given the other variables in the model are held constant, the multinomial log-odds of becoming Minimal

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to Severe would be expected to be unchanged; (2) Moderate relative to Severe: for a one unit increase in ADT for moderate relative to Severe given the other variables in the model are held constant, the multinomial log-odds of becoming Moderate to Severe would be expected to be unchanged.

For Minimal relative to Severe, the Wald test statistic for the predictor ADT is 0 with an associated p-value of 0.996. Therefore, it would fail to reject the null hypothesis and conclude that for Minimal relative to Severe, the regression coefficient for ADT has not been found to be statistically different from zero. The same conclusions would be expected for Moderate relative to Severe.

Both ordinal and multinomial logistic regression show that there is no significant association between ADT and SEVERITY. But this conclusion should be verified by creating a comprehensive model considering all other predictors.

4.3.2 Sample Two

An ordinal regression was carried out at first and the output is shown in Table 4.31 ~ Table 4.33. Even though the model from the ordinal regression seems to fit the relationship well, the test of parallel lines shows that the null hypothesis that the slope coefficients in the model are the same across response categories is violated. Multinomial logistic regression was conducted as another analysis to compare with ordinal regression, and the results are shown in Table 4.34 and Table 4.35.
Table 4.31 Sample Two: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1234.091			
Final	1192.759	41.332	1	.000

between ADT and SEVERITY

Table 4.32 Sample Two: Parameter estimates of ordinal logistic regression between

ADT and SEVERITY

		Std. Estimate	Wald	df	Sig.	95% Co Inte	nfidence rval	
			Error				Lower	Upper
							Bound	Bound
Threshold	[SEVERITY = 1.00]	520	.096	29.317	1	.000	709	332
	[SEVERITY = 2.00]	1.572	.116	183.621	1	.000	1.344	1.799
Location	ADT	3.322E- 5	6.180E- 6	28.903	1	.000	2.111E-5	4.534E-5

Table 4.33 Sample Two: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	1192.759			
General	1185.952	6.807	1	.009
	11001/01	0.007	1	

ADT and SEVERITY

Table 4.34 Sample Two: Model fitting information of multinomial logistic regression

	Model Fitting Criteria			Likelihood Ratio Tests		
Model	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1238.091	1246.885	1234.091			
Final	1194.964	1212.552	1186.964	47.127	2	.000

• AIC: This is the Akaike information criterion.

• BIC: This is the Bayesian information criterion.

 Table 4.35 Sample Two: Parameter estimates of multinomial logistic regression

								95% Co	nfidence
SEVERITY	ERITY	B Std.	Std.	Wald	df	Sig.	Exp(B)	Interval for	or Exp(B)
			Error					Lower	Upper
								Bound	Bound
	Intercept	.852	.141	36.785	1	.000			
1.00									
	ADT	.000	.000	24.038	1	.000	1.000	1.000	1.000
	Intercept	.905	.123	54.330	1	.000			
2.00									
	ADT	.000	.000	10.356	1	.001	1.000	1.000	1.000

between ADT and SEVERITY

Note: The reference category is 3.

Table 4.36 Sample	Two: Classific	cation table of :	multinomial lo	gistic regression
···· · · · · · · · · · · · · · · · · ·				

between ADT and SEVERITY

	Predicted					
Observed	1.00	2.00	3.00	Percent		
	1.00	2.00	5.00	Correct		
1.00	0	191	1	0.0%		
2.00	0	267	6	97.8%		
3.00	0	122	13	9.6%		
Overall Percentage	0.0%	96.7%	3.3%	46.7%		

Table 4.36 indicates this multinomial logit model is statistically significant and fits the relationship well. For Minimal relative to Severe, the Wald test statistic for the predictor ADT is 24.038 with an associated p-value of 0.0001. Therefore, the null hypothesis would be rejected and conclude that for Minimal relative to Severe, the regression coefficient for ADT has been found to be statistically different from zero. The same conclusions would be expected for Moderate relative to Severe.

4.3.3 Conclusions

The test of parallel lines of ordinal logistic regression between ADT and SEVERITY has shown that the null regression that the slope coefficients in the model are the same across response categories is violated both for sample one and sample two. Method of multinomial logistic regression was used to obtain the relationship between ADT and SEVERITY. The analysis for sample one shows the model cannot reflect the relationship between ADT and SEVERITY with an associated model p-value around 0.1. While the analysis for sample two demonstrates that ADT is statistically significant for the model. The table of parameter estimates for sample two shows that a 0.00003 increase in the ordered log odds of being in a higher level of settlement for a one unit increase in ADT, which means the higher of settlement level may occur as the ADT is larger.

The biggest difference between these two samples are data size. Therefore, this study believes that there is an association between ADT and SEVERITY given sufficient sample size. This conclusion should be compared to the conclusions from the comprehensive model taking all other predictors into account. Table 4.36 gives the classification table of multinomial logistic regression between ADT and SEVERITY. The overall (correct) percentage of predicting the settlement levels sorely based on ADT is 46.7%, which is not an ideal predicted accuracy in engineering area.

4.4 Approach Type

Many researchers, Ha et al. (2002), Luna et al. (2003), White et al. (2005), Puppla et al. (2009), applied approach slabs on selected sites to connect roadway and bridges and practiced the bump problems at bridge ends that could be minimized when an approach slab is used. Investigations from Dopont and Allen (2002) and Briaud et al. (1997) have illustrated that approach slabs are widely perceived as successful when they are designed longer to span the problematic area and stronger to prevent cracking as well as the fact that good pavement joints lead into them. However, these conclusions were derived from a specific survey or field tests, no systematic statistical method has been used to verify the good performance of approach slabs in solving bump issues.

Concerning fewer approach slabs are used in Kentucky, this section intends to verify whether approach slabs are useful or not on mitigating bump problem based on the performance of approach slabs that have been constructed in Kentucky.

4.4.1 Sample One

Table 4.37 presents the statistics of sample one that was used to explore the relationship between approach type and differential settlement scale. A mosaic plot (Figure 4.17) was created to explore the distribution of a categorical (nominal or ordinal) variable SEVERITY across the levels of a second categorical variable APPT. A mosaic plot is divided into rectangles, so that the area of each rectangle is proportional to the populations of the Y variable in each level of the x variable. The larger the rectangle area, the greater number of count data in it. Note the following about Figure 4.17:

- The proportions on the x-axis represent the number of observations for each level of the x variable, which is approach type (APPT).
- The proportions on the y-axis at right represent the overall proportions of Minimal, Moderate, and Severe settlements for the combined levels (All different approach types).
- The scale of the y-axis at left show the response probability, with the whole axis being a probability of one (representing the total sample).

The mosaic plot shows that the bridges with rigid approaches both have higher proportions of minimal settlement and severe settlement than the bridges with flexible approaches. While the bridges with flexible approaches have a higher proportion of moderate settlement.

Approach		Severity				
Туре	Minimal Moderate Severe			Total		
Flexible (0)	11	31	28	70		
Rigid (1)	3	5	9	17		
Total	14	36	37	87		

Table 4.37 Sample One:	Frequency table of approach t	ype (APPT) by SEVERITY
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Figure 4.17 Sample One: Distribution of settlement levels across approach type

A model was attempted to be created to describe the relationship between APPT and SVERITY by SPSS, and the output is shown in Table 4.38 ~ Table 4.40. The results indicate that this model cannot fit the relationship well and there is no direct association between APPT and SEVERITY based on the regression coefficients of APPT for SEVERITY.

 Table 4.38 Sample One: Model fitting information of ordinal logistic regression

 between APPT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	15.796			
Final	15.309	.487	1	.485

							95% Co	nfidence
			Std.		10	a.	Interval	
		Estimate	Error	wald	đr	51g.	Lower	Upper
							Bound	Bound
	·							
	[SEVERITY	-1 957	520	14 190	1	000	-2 976	- 939
	= 1.00]	1.757	.520	14.170	1	.000	2.770	.,,,,,
Threshold								
	[SEVERITY	002	169	000	1	005	012	010
	= 2.001	.003	.468	.000	1	.995	913	.919
]							
	[APPT=.00]	367	.516	.505	1	.477	-1.378	.645
Location								
	[APPT=1.00]	0 ^a	•		0			

APPT and SEVERITY

a. This parameter is set to zero because it is redundant.

Table 4.40 Sample One: Test of parallel lines of ordinal logistic regression between

APPT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	15.309			
General	14.461	.848	1	.357

Another method used to assess whether two categorical variables, APPT and

SEVERITY, are independent or not is Chi-square test. The test procedure is appropriate

when the following conditions are met:

- 1. The sampling method is simple random sampling.
- 2. The variables under study are each categorical.
- 3. If sample data are displayed in a contingency table, the expected frequency count for each cell of the table is at least 5.

Sample one was created from a survey and cannot meet the condition 1. From contingency table 4.37, several cells have a small frequency count. Therefore, Chi-square test is not appropriate for sample one.

4.4.2 Sample Two

A descriptive analysis was conducted by creating a frequency table of approach type by settlement levels and a mosaic plot of distribution of settlement levels across approach type. The mosaic plot reveals that the bridges with rigid approach tend to experience minimal settlement and have the lowest proportion of severe settlement. A measure to further explore the functional relationship between APPT and SEVERITY was analyzed by ordinal logistic regression in SPSS.

Approach		Severity		
Туре	Minimal	Moderate	Severe	Total
Flexible (0)	134	218	115	467
Rigid (1)	58	55	20	133
Total	192	273	135	600

Table 4.41 Sample Two: Frequency table of approach type (APPT) by SEVERT	JKI I Y
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Figure 4.18 Sample Two: Distribution of settlement levels across approach type

 Table 4.42 Sample Two: Model fitting information of ordinal logistic regression

between APPT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	34.402			
Final	22.444	11.957	1	.001

Table 4.43 Sample Two: Parameter estimates of ordinal logistic regression between

							95% Co	nfidence
			Std.	Wald	df	Sig	Interval	
		Lotinute	Error	vv ard	ui	Sig.	Lower	Upper
							Bound	Bound
Threads all d	[SEVERITY = 1.00]	265	.166	2.558	1	.110	591	.060
Inresnoid	[SEVERITY = 2.00]	1.756	.182	93.134	1	.000	1.399	2.113
Location	[APPT=.00]	.641	.186	11.835	1	.001	.276	1.007
	[APPT=1.00]	0 ^a	•		0		•	

APPT and SEVERITY

a. This parameter is set to zero because it is redundant

Table 4.44 Sample Two: Test of parallel lines of ordinal logistic regression between

APPT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	22.444			
General	22.422	.022	1	.881

This model can fit the relationship between APPT and SEVERITY well with a model pvalue 0.001. The table of parameter estimates show the Wald test statistic for the predictor APPT is 11.835 with an associated p-value of 0.001. The null hypothesis that the regression coefficient of APPT is zero given that the rest of the predictors are in the model (only one predictor in this model) would be rejected. In other words, APPT is statistically significant to this model and a relationship exists between APPT and SEVERITY.

To further verify there is a significant association between APPT and SEVERITY, Chisquare test has been undertaken. This method consists of four steps: (1) state the hypothesis, (2) formulate an analysis plan, (3) analyze sample data, and (4) interpret results.

1. State the hypothesis

The null hypothesis states that knowing the level of approach type is not helpful to predict the level of settlement severity. That is, the two categorical variables are independent.

 H_0 : Approach type and settlement severity are independent H_a : Approach type and settlment severity are not independent The alternative hypothesis is that knowing the approach type is helpful to predict the level of settlement severity. However, support for the alternative hypothesis suggests that APPT and SEVERITY are related, the relationship is not necessarily causal. In the sense that APPT "causes" the other.

2. Formulate an analysis plan

A significance level of 0.05 is specified and Chi-square test is used to examine whether these two variables are independent or not.

3. Analyze sample data

Using sample data, calculate the degrees of freedom, expected frequencies, test statistic, and the P-value associated with the test statistic.

Degrees of freedom: The degrees of freedom (DF) is equal to:

$$DF = (r-1) * (c-1)$$
(4.8)

where r is the number of levels for one categorical variable, and c is the number of levels for the other categorical variable. In this case, DF is equal to 2. Expected frequencies: The expected frequency counts are computed separately for each level of one categorical variable at each level of the other categorical variable. Compute r * c expected frequencies by using the following equation.

$$E_{r,c} = (n_r * n_c)/n$$
 (4.9)

where $E_{r,c}$ is the expected frequency count for level of r of APPT and level c of SEVERITY, n_r is the total number of sample observations at level r of APPT, n_c is the total number of sample observations at level c of SEVERITY, and n is the total sample size. Table 4.45 shows the observed frequencies and expected frequencies.

				Total		
		Minimal	Moderate	Severe	Total	
	Flexible	Count	134	218	115	467
АРРТ	1 10/11010	Expected Count	149.4	212.5	105.1	467.0
Rigid	Rigid	Count	58	55	20	133
	Expected Count	42.6	60.5	29.9	133.0	
Total		Count	192	273	135	600
		Expected Count	192.0	273.0	135.0	600.0

Table 4.45 Sample Two: APPT VS. SEVERITY cross tabulation

Test statistic: The test statistic is a Chi-square random variable (x^2) defined by the following equation.

$$X^{2} = \sum \left[(O_{r,c} - E_{r,c})^{2} / E_{r,c} \right]$$
(4.10)

where $O_{r,c}$ is the observed frequency count at level r of APPT and level c of SEVERITY. The test statistic in this case is 12.01. The p-value is the probability that a Chi-square statistic having two degrees of freedom is more extreme than 12.01. By using the Chi-square Distribution Calculator to find $P(x^2 > 12.01) = 0.002$.

P-value: The P-value is the probability of observing a sample statistic as extreme as the test statistic. Table 4.46 presents the result of Chi-square test using SPSS, which is the same with the result calculated by using Chi-square Distribution Calculator.

	Valua	df	Asymp. Sig. (2-
	value	u	sided)
Pearson Chi-Square	12.072	2	.002
Likelihood Ratio	11.980	2	.003
Linear-by-Linear Association	11.577	1	.001
N of Valid Cases	600		

Table 4.46 Sample Two: Chi-square test for APPT VS. SEVERITY

4. Interpret results

Since the p-value (0.002) is much smaller than the significance level (0.05), we cannot accept the null hypothesis. Thus, 99.8% probability to conclude that there is a correlation between APPT and SEVERITY.

The Chi-square test has verified there is a significant relationship between approach type and settlement severity, however, a positive or negative impact is not specified, even with its effectiveness magnitude. A rating system as illustrated in Table 4.47 is defined to quantify the effectiveness of rigid approach on mitigating differential settlement. Grade 3, 2, and 1 would be assigned to settlement level minimal, moderate, and severe, respectively.

Settlement Scale	Grade	Effective Ratio	Impact
Minimal	2	1	No impact
Moderate	1	<1	Negative
Severe	0	>1	Positive

Table 4.47 Sample Two: Rating system to quantify approach effectiveness

An effective ratio (ER) is defined as:

ER

 $= \frac{Total grade of rigid approaches in different settlement level}{Count of rigid approac} (4.11)$ $= \frac{Total grade of flexible approaches in different settlement level}{Count of flexible appr}$

By this method, it is appropriate to conclude the approach slab would generate a positive impact on mitigating differential settlement when ER is larger than 1, otherwise, a negative impact would take place when ER is less than 1, or no impact of approach slab use when ER equals 1. The ER of the sample two is equal to1.24. Thus, the use of approach slab has a positive effect on mitigating the problem caused by differential settlement. In other words, the use of approach slabs could enhance the performance of approaches as transitions between roadway and the bridge. However, the effectiveness is not significant because the ER is slightly larger than 1.

Table 4.48 Sample Two: Grade distribution for approach type in different

Category		Flexible			Rigid	
SEVERITY	Minimal	Moderate	Severe	Minimal	Moderate	Severe
Count	134	218	115	58	55	20
Grade	268	218	0	116	55	0

settlement severity

4.4.3 Conclusions

The mosaic plots of sample one and sample two both show that the bridges with rigid approaches tend to present a higher proportion in minimal settlement than flexible approaches. The ordinal regression of sample one shows that there is no association between APPT and SEVERITY. While, the SPSS output of sample two indicates that APPT is statistically significant in the relationship between APPT and SEVERITY. The ordered logit for flexible approaches being in a higher settlement level is 0.641 more than rigid approaches when the other variable in the models are held constant (only one predictor for this model). In other words, the regression output of sample two indicates that rigid approaches behave better than flexible approaches in the treatment of the differential settlement at bridge ends. The results of Chi-square test for sample two verify the conclusion that there is a significant association between APPT and SEVERITY. An effective ration was defined to illustrate the impact of approach slabs on mitigating differential settlement. The result indicates that the use of approach slab has a positive effect on mitigating the problem caused by differential settlement at bridge ends.

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4.5 Abutment Type

4.5.1 Sample One

A descriptive analysis was conducted by creating a frequency table of abutment type by settlement levels and a mosaic plot of distribution of settlement levels across abutment type. The mosaic plot reveals that the bridges with perched abutments have the highest proportion of minimal settlement compared to other abutment types. A measure to further explore the relationship between ABUT and SEVERITY was analyzed by ordinal logistic regression in SPSS. The output shows that the model cannot fit the relationship between ABUT and SEVERITY are two independent variables (no association between ABUT and SEVERITY).

Abutment Type		Total			
ributilient Type	Minimal	Moderate	Severe	1 otur	
Closed (1)	3	7	8	18	
Spill-through (2)	0	6	4	10	
Perched (3)	11	23	25	59	
Total	14	36	37	87	

Table 4.49 Sample One: Frequency table of abutment type (ABUT) by SEVERITY



Figure 4.19 Sample One: Distribution of settlement levels across abutment type

 Table 4.50 Sample One: Model fitting information of ordinal logistic regression

	between	ABUT	and	SEV	'ERI'I	ľΥ
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Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	21.469			
Final	21.247	.222	2	.895

Table 4.51 Sample One: Parameter estimates of ordinal logistic regression between

							95% Co	nfidence
		Fstimate	Std.	Wold	df	Sig	Interval	
		Listinute	Error	vv ard	ui	Sig.	Lower	Upper
							Bound	Bound
	[SEVERITY = 1.00]	-1.596	.320	24.912	1	.000	-2.223	969
Threshold								
	[SEVERITY = 2.00]	.360	.259	1.936	1	.164	147	.867
	[ABUT=1.00]	.104	.507	.042	1	.838	890	1.097
Location	[ABUT=2.00]	.279	.650	.184	1	.668	994	1.552
	[ABUT=3.00]	0 ^a	•	•	0	•	•	•

ABUT and SEVERITY

a. This parameter is set to zero because it is redundant.

Table 4.52 Sample One: Test of parallel lines of ordinal logistic regression between

ABUT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	21.247			
General	17.143	4.104	2	.128

4.5.2 Sample Two

Table 4.53 shows the frequency table of abutment type by severity levels for sample two. Figure 4.20 presents a mosaic plot illustrating the distribution of SEVERITY across ABUT. It shows that the bridges with perched abutments have the highest proportion of minimal settlement.

Abutment Type		Total		
rioutilient Type	Minimal	Moderate	Severe	Total
Closed (1)	44	69	38	151
Spill-through (2)	10	42	20	72
Perched (3)	138	162	77	377
Total	192	273	135	600

 Table 4.53 Sample Two:
 Frequency table of abutment type (ABUT) by SEVERITY



Figure 4.20 Sample Two: Distribution of settlement levels across abutment type

Table 4.54 Sample Two: Model fitting information of ordinal logistic regression

between ABUT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	48.028			
Final	36.593	11.435	2	.003

Table 4.55 Sample Two: Parameter estimates of ordinal logistic regression between

	E	Std. Estimate	Std.	Wald	df	df Sig.	df Sig.		nfidence rval
			Error				Lower	Upper Bound	
							Doulid	Dound	
	[SEVERITY = 1.00]	589	.103	32.456	1	.000	792	386	
Threshold									
	[SEVERITY = 2.00]	1.433	.119	145.761	1	.000	1.200	1.665	
	[ABUT=1.00]	.320	.180	3.139	1	.076	034	.673	
Location	[ABUT=2.00]	.749	.242	9.572	1	.002	.275	1.224	
	[ABUT=3.00]	0 ^a	•	•	0	•	•	•	

ABUT and SEVERITY

Table 4.56 Sample Two: Test of parallel lines of ordinal logistic regression between

ABUT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	36.593			
General	30.892	5.701	2	.058

Ordinal regression was implemented to identify the functional relationship between ABUT and SEVERITY. The output is shown in Table 4.54 ~ Table 4.56. The model fit

information shows that this model fits significantly better than an empty model (i.e., a model with no predictors). The table of parameter estimates shows that ABUT=2 (spill-through) is statistically significant. The log odds of being in a higher settlement level will increase by 0.320 if moving from the ABUT=3 (perched) to the ABUT=1 (closed). Similarly, the log odds of being in a higher settlement level will increase by 0.749 if moving from the ABUT=3 (perched) to the ABUT=2 (spill-through). In other words, the bridges with perched abutment experience a lower level of settlement compared to other types of abutment given other independent variables are the same.

Generally, the interpretation for logistic regression between two nominal variables is very cumbersome, especially the outcome variable and independent variables have more than two levels. In this instance, the output from a mosaic plot can be helpful to explore the relationship between two categorical variables. The logistic regression can be used to define the functional relationship between two categorical variables.

4.5.3 Conclusions

The mosaic plots of sample one and sample two both show that the bridges with perched abutment tend to present a higher proportion in minimal settlement than other types of abutment. The SPSS output of sample one indicates there is no association between ABUT and SEVERITY. While the output of sample two indicates a relationship exist between ABUT and SEVERITY. The interpretation of parameter estimates of sample two concludes that: (1) the log odds of being in a higher settlement level will increase by 0.320 if moving from the ABUT=3 (perched) to the ABUT=1 (closed), and (2) the log odds of being in a higher settlement level will increase by 0.749 if moving from the ABUT=3 (perched) to the ABUT=2 (spill-through). Sample two demonstrates that the

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bridges with perched abutment experience a lower level of settlement compared to other types of abutment given other independent variables are the same.

4.6 Embankment Height

4.6.1 Sample One

A scatterplot of approach settlement levels by embankment height of sample one is given in Figure 4.21. This plot cannot provide a clear picture of the nature of the relationship between EH and SEVERITY. In addition, a frequency table of embankment height group (EHG) by SEVERITY is used to group the independent variable EG into four categories defined in Table 4.57. The EHG of 0~20 feet shows a higher proportion of settlement in minimal than the group of above 20 feet. While EHG of above 20 feet shows a higher proportion of settlement in severe than the group of 0~20 feet. The output from SPSS shows that the null hypothesis that the regression coefficient in the model is equal to zero cannot be rejected because the p-value of the model is 0.847. In other words, this model is not better than a null model without any predictors and cannot reflect the relationship between EH and SEVERITY.





height

Table 4.57 Sample One: Frequency table of embankment height group (EHG) by

SEVERITY

EH group		Severity		Total	Me	ean
(feet)	Minimal	Moderate	Severe	Totui	Minimal	Severe
0~10	4	10	11	25	0.160	0.440
11~20	8	15	13	36	0.222	0.361
21~30	1	6	9	16	0.063	0.563
Above 30	1	5	4	10	0.100	0.400
Total	14	36	37	87		

Table 4.58 Sample One: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	111.179			
Final	111.142	.037	1	.847

between EH and SEVERITY

Table 4.59 Sample One: Parameter estimates of ordinal logistic regression between

EH and SEVERITY

					d df	Sig.	95% Co	nfidence
		Estimate	Std.	Wald			Inte	rval
			Error				Lower	Upper
							Bound	Bound
	[SEVERITY	-1.597	.407	15.373	1	.000	-2.396	799
Threshold	= 1.00]							
	[SEVERITY	.356	.361	.970	1	.325	352	1.064
	= 2.00]							
Location	EH	.003	.017	.034	1	.853	030	.036

Table 4.60 Sample One: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	111.142			
General	110.380	.762	1	.383

EH and SEVERITY

4.6.2 Sample Two

A descriptive analysis was conducted by creating a scatterplot of approach settlement levels by embankment height and a frequency table of embankment height group (EHG) by SEVERITY. The EHG of 0~10 feet shows the highest proportion of settlement in minimal than the other groups. While EHG of above 20 feet shows a higher proportion of settlement in severe than the group of 0~20 feet. The output from SPSS shows that the null hypothesis that the regression coefficient in the model is equal to zero would be rejected because the p-value of the model is 0.003. In other words, this model is significantly better than a null model without any predictors. The relationship between EH and Severity should be identified by comparing to a comprehensive model considering all other independent variables.



Figure 4.22 Sample Two: Scatterplot of approach settlement levels by embankment

height

Table 4.61 Sample Two: Frequency table of embankment height group (EHG) by

EH group	Severity			Total	Me	ean
(feet)	Minimal	Moderate	Severe	Totui	Minimal	Severe
0~10	127	145	81	333	0.381	0.243
11~20	38	78	40	156	0.243	0.256
21~30	14	32	21	67	0.209	0.313
Above 30	13	18	13	44	0.295	0.295
Total	192	273	135	600		

Table 4.62 Sample Two: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	304.684			
Final	295.877	8.807	1	.003

between EH and SEVERITY

Table 4.63 Sample Two: Parameter estimates of ordinal logistic regression between

EH and SEVERITY

							95% Co	nfidence
			Std.	Wald	df	Sig.	Interval	
			Error				Lower	Upper
							Bound	Bound
	[SEVERITY = 1.00]	512	.119	18.577	1	.000	745	279
Threshold								
	[SEVERITY = 2.00]	1.502	.134	125.068	1	.000	1.239	1.766
Lestian	EII	021	007	0.016	1	002	007	024
Location	EH	.021	.007	8.840	1	.003	.007	.034

Table 4.64 Sample Two: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	295.877			
General	295.876	.001	1	.978

EH and SEVERITY

4.6.3 Conclusions

Scatterplots of approach settlement levels by embankment height for sample one and sample two cannot provide a clear picture of the relationship between EH and SEVERITY. For sample one, the embankment height group of 11~20 feet presents the highest proportion of approaches with minimal settlement. For sample two, the embankment height group of 0~10 feet presents the highest proportion of approaches with minimal settlement tend to settle less than deep embankment. In return, group of above 30 feet presents the highest proportion of approaches with severe settlement for sample one and group of 21~30 feet presents the highest proportion of approaches with severe settlement for sample one and group of 21~30 feet presents the highest proportion of approaches with severe settlement for sample two. Both samples show that deep embankment tend to settle more than shallow embankment.

The SPSS output for sample one and sample two are different. The model of sample two is better to reflect a relationship between EH and SEVERITY than a null model without any predictors. The model of sample two shows that the ordered log odds of being in a higher level of settlement will increase 0.021 for a one unit increase in embankment height. In other words, the higher the embankment, the higher level of settlement may occur. However, this model cannot identify the exact relationship between EH and SEVERITY. All other predictors should be considered to create a comprehensive model to define the relationship between EH and SEVERITY by comparing to other independent variables.

4.7 Foundation Soil Depth

4.7.1 Sample One

A scatterplot of approach settlement levels by foundation soil depth was given for a descriptive analysis, but this plot cannot provide a clear picture of the relationship between FSD and SEVERITY. Then a frequency table of foundation soil depth by severity was created to figure out the changing tendency of the proportion of approaches with minimal settlement and severe settlement. Table 4.65 shows that shallow foundations have a higher proportion of settlement in minimal than deep foundations. The functional relationship between FSD and SEVERITY was attempted to be identified by SPSS. The output shows that the regression coefficient of FSD for SEVERITY is 0.942, which implies that there is no association between FSD and SEVERITY. Moreover, the model is not different from a null model and cannot fit the relationship well.

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Figure 4.23 Sample One: Scatterplot of approach settlement levels by foundation

soil depth

Table 4.65 Sample One: Frequency table of foundation soil depth (FSD) by

FSD (feet)		Severity		Total	Mean		
1 SD (leet)	Minimal	Moderate	Severe	Totai	Minimal	Severe	
0~10	5	12	14	31	0.161	0.452	
11~20	4	13	11	28	0.143	0.393	
21~30	4	4	6	14	0.286	0.429	
31~40	1	3	3	7	0.143	0.429	
Above 40	0	4	3	7	0	0.429	
	14	36	37	87			

SEVERITY

Table 4.66 Sample One: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	102.216			
Final	102.211	.006	1	.940

between FSD and SEVERITY

Table 4.67 Sample One: Parameter estimates of ordinal logistic regression between

FSD and SEVERITY

							95% Co	nfidence
			Std.	Wald	df	Sig	Interval	
		Lstimate	Error	ward	ui	Sig.	Lower	Upper
							Bound	Bound
	[SEVERITY = 1.00]	-1.635	.370	19.550	1	.000	-2.359	910
Threshold								
	[SEVERITY = 2.00]	.318	.315	1.017	1	.313	300	.936
Location	FSD	001	014	005	1	042	027	020
Location	1.20	.001	.014	.005	1	.742	027	.029

Table 4.68 Sample One: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	102.211			
General	101.998	.212	1	.645

FSD and SEVERITY

4.7.2 Sample Two

No distinct relationship between FSD and SEVERITY is found by examining the scatterplot of approach settlement levels by foundation soil depth. The frequency table of FSD by SEVERITY shows that shallow foundations are more likely to present a higher settlement level than deep foundations. The output from the ordinal logistic regression indicates that there is an association between FSD and SEVERITY. For a unit increase in FSD, the log odds of being in a higher level of settlement would be expected to decrease 0.018.



Figure 4.24 Sample Two: Scatterplot of approach settlement levels by foundation

soil depth

Table 4.69 Sample Two: Frequency table of foundation soil depth (FSD) by

		Severity		- 1	Me	ean
FSD (feet)				Total		1
	Minimal	Moderate	Severe		Minimal	Severe
0~10	59	127	75	261	0.226	0.287
11~20	32	33	20	85	0.376	0.235
21~30	18	21	9	48	0.375	0.188
31~40	21	37	10	68	0.309	0.147
Above 40	62	55	21	138	0.449	0.152
	192	273	135	600		

SEVERITY
Table 4.70 Sample Two: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	271.677			
Final	250.393	21.285	1	.000

between FSD and SEVERITY

Table 4.71 Sample Two: Parameter estimates of ordinal logistic regression between

FSD and SEVERITY

							95% Co	nfidence
		Std. Estimate		Wald	df	Sig.	Interval	
			Error				Lower	Upper
							Bound	Bound
	[SEVERITY	1 1 2 7	104	94 670	1	000	1 270	205
	= 1.00]	-1.137	.124	04.070	1	.000	-1.379	095
Threshold								
	[SEVERITY	.910	.120	57.677	1	.000	.675	1.145
	= 2.00]							
Leastion	ECD	019	004	20.707	1	000	026	010
Location	FSD	018	.004	20.797	I	.000	026	010

Table 4.72 Sample Two: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	250.393			
General	250.392	.001	1	.980

FSD and SEVERITY

4.7.3 Conclusions

Descriptive analysis of sample one indicates that shallow foundations are tend to have a lower level of settlement compared to deep foundations. While the results from sample two reverse this conclusion. Ordinal logistic regression of sample one shows that there is no association between FSD and SEVERITY, while the sample two shows that for a one unit increase in FSD, a 0.018 decrease in the ordered log odds of being in a higher level of settlement would be expected. Note that the frequency table of FSD by SEVERITY of sample one has empty cells, which may lead to an unstable model for interpretation.

4.8 Foundation Soil Consistency

4.8.1 Sample One

No distinct relationship between FSC and SEVERITY is found by examining the scatterplot of approach settlement levels by foundation soil depth. The mosaic plot of settlement levels across foundation soil consistency shows that the proportion of approaches in minimal settlement varies slightly in each of group of consistency. In

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addition, the model from ordinal logistic regression reveals that the model cannot reflect the relationship and there is no association between FSC and SEVERITY.

Table 4.73 Sample One: Frequency table of foundation soil consistency (FSC) by

ESC (level)		Total		
	Minimal	Moderate	Severe	Total
Soft	1	4	2	7
Stiff	5	11	15	31
Very stiff	5	13	12	30
Hard	3	8	8	19
Total	14	36	37	87

SEVERITY





Table 4.74 Sample One: Model fitting information of ordinal logistic regression

between FSC and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	25.498			
Final	24.904	.594	3	.898

Table 4.75 Sample One: Parameter estimates of ordinal logistic regression between

		Estimate Std.		Wald	df	Sig	95% Confidence Interval	
		Listimute	Error	W uid		515.	Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-1.652	.481	11.812	1	.001	-2.595	710
	[SEVERITY = 2.00]	.310	.439	.500	1	.480	550	1.171
	[FSC=1.00]	339	.827	.168	1	.682	-1.960	1.283
Location	[FSC=2.00]	.186	.550	.115	1	.735	892	1.264
	[FSC=3.00]	080	.551	.021	1	.885	-1.159	1.000
	[FSC=4.00]	0	•		0	•		

FSC and SEVERITY

Table 4.76 Sample One: Test of parallel lines of ordinal logistic regression between

FSC and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	24.904			
General	24.149	.756	3	.860

4.8.2 Sample Two

The mosaic plot of settlement levels across foundation soil consistency shows that the group of hard of foundation soil consistency has the lowest proportion in minimal settlement while has the highest proportion in severe settlement. The SPSS output shows that there is an association between FSC and SVERITY and the model is significantly better than a null model without any predictors. The logit odds of being in a higher level of settlement will decrease by 0.432 if moving from FSC=4 (hard) to FSC=1 (soft). The logit odds of being in a higher level of settlement will decrease by 0.528 if moving from FSC=4 (hard) to FSC=3 (very stiff). In other words, the approaches with a higher level of foundation soil consistency tend to experience a lower level of settlement.

 Table 4.77 Sample Two: Frequency table of foundation soil consistency (FSC) by

 SEVERITY

FSC (level)		Severity					
	Minimal	Moderate	Severe	Total			
Soft	12	16	7	35			
Stiff	62	74	34	170			
Very stiff	65	71	35	171			
Hard	53	112	59	224			
Total	192	273	135	600			





Table 4.78 Sample Two: Model fitting information of ordinal logistic regression

between FSC and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	51.727			
Final	41.439	10.288	3	.016

Table 4.79 Sample Two: Parameter estimates of ordinal logistic regression between

			Std.		df	Sig	95% Confidence Interval	
			Error			~ 6	Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-1.076	.137	62.020	1	.000	-1.344	808
	[SEVERITY = 2.00]	.942	.135	49.020	1	.000	.679	1.206
	[FSC=1.00]	432	.340	1.614	1	.204	-1.099	.235
Location	[FSC=2.00]	494	.191	6.680	1	.010	868	119
	[FSC=3.00]	528	.191	7.638	1	.006	902	153
	[FSC=4.00]	0	•	•	0	•	•	•

FSC and SEVERITY

Table 4.80 Sample Two: Test of parallel lines of ordinal logistic regression between

FSC and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	41.439			
General	39.446	1.993	3	.574

4.8.3 Conclusions

The descriptive analysis of sample one and sample two cannot provide a clear picture of the relationship between FSC and SVERITY. The ordinal logistic regression of sample one shows that there is no association between FSC and SEVERITY, while the sample two shows that FSC is statistically significant. The mosaic plot of sample two shows that the group of hard foundation soil consistency has the lowest proportion in minimal settlement while has the highest proportion in severe settlement. But the functional relationship gained by SPPS indicates that the approaches with a higher level of foundation soil consistency tend to experience a lower level of settlement.

4.9 Geographical Location

Table 4.81 lists the two samples with different approach settlement levels in each district. For sample one, there is no data from district two, three, and eight. For sample two, there are few data from district four and eight. From the mosaic plot of distribution of settlement levels across each district of sample one, district eleven presents the highest proportion of approaches with minimal settlement while the relatively small proportion of approaches with severe settlement. District twelve presents the highest proportion of approaches with severe settlement. The mosaic plot of sample two shows that the district one and district ten behaves much better than other districts with the highest proportion in minimal settlement while the lowest proportion in severe settlement.

	Sample One				Sample Two				
District		Severity		Total		Severity	Severity		
	Minimal	Moderate	Severe	Total	Minimal	Moderate	Severe	Total	
1	1	2	1	4	97	65	5	167	
2	0	0	0	0	0	6	12	18	
3	0	0	0	0	11	13	4	28	
4	0	2	2	4	0	0	1	1	
5	0	10	1	11	1	17	18	36	
6	5	9	16	30	11	39	18	68	
7	0	4	5	9	7	25	40	72	
8	0	0	0	0	0	1	1	2	
9	0	3	2	5	3	16	11	30	
10	1	1	1	3	21	13	0	34	
11	7	5	6	18	5	31	9	45	
12	0	0	3	3	36	47	16	99	
	14	36	37	87	192	273	135	600	

Table 4.81 Distribution of the Bridge Approaches from Each District



Figure 4.27 Sample One: Distribution of settlement levels across transportation district



Figure 4.28 Sample Two: Distribution of settlement levels across transportation district

Ordinal logistic regression was performed at first for both samples to explore the functional relationship between DISTRICT and SEVERITY. The test of parallel lines of sample one shows that the null hypothesis states that the slope coefficients are the same across response categories is violated. Therefore, multinomial logistic regression was carried out for sample one. The output of multinomial logistic regression for sample one and ordinal logistic regression for sample two is shown in the following tables.

 Table 4.82 Sample One: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	47.844			
General	28.160	19.684	8	.012

DISTRICT and SEVERITY

 Table 4.83 Sample One: Model fitting information of multinomial logistic regression

between district and SEVERITY

	Мо	Model Fitting Criteria		Likelihood Ratio Tests		
Model	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	64.942	69.873	60.942			
Final	63.434	73.297	55.434	5.508	2	.064

Table 4.84 Sample One: Parameter estimates of multinomial logistic regression

								95% Co	nfidence
SE	VERITY	В	Std.	Wald	df	Sig.	Exp(B)	Interval fo	or Exp(B)
			Error					Lower	Upper
								Bound	Bound
	Intercept	-2.056	1.014	4.109	1	.043			
1.00									
	DISTRICT	.137	.118	1.340	1	.247	1.146	.910	1.445
	Intercept	.881	.667	1.742	1	.187			
2.00									
	DISTRICT	130	.090	2.111	1	.146	.878	.736	1.047

between DISTRICT and SEVERITY

Note: The reference category is: 3.00

Table 4.85 Sample One: Parameter estimates of multinomial logistic regression

between DISTRICT and SEVERITY

	Predicted				
Observed	1.00	2.00	3.00	Percent	
	1.00	2.00	2100	Correct	
1.00	0	6	8	0.0%	
2.00	0	23	13	63.9%	
3.00	0	20	17	45.9%	
Overall Percentage	0.0%	56.3%	43.7%	46.0%	

By analyzing the output from the multinomial logistic regression for sample one, the pvalue of the model is slightly larger than 0.05. It is uncertain to conclude that there is an association between DISTRICT and SEVERITY for sample one. All other predictors should be considered to create a comprehensive model to evaluate the relationship between DISTRICT and SEVERITY. The interpretation of the parameter estimates is not given here because it may lead to ambiguity.

 Table 4.86 Sample Two: Model fitting information of ordinal logistic regression

 between DISTRICT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	297.488			
Final	84.835	212.653	11	.000

DISTRICT	and	SEVERITY
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							95% Confidence	
		Estimato	Std.	Wald	1 df	Sig	Interval	
		Estimate	Error	w alu	vi ulu ul	Sig.	Lower	Upper
							Bound	Bound
Threshold	[SEVERITY = 1.00]	699	.199	12.304	1	.000	-1.089	308
	[SEVERITY = 2.00]	1.992	.225	78.050	1	.000	1.550	2.434
	[DISTRICT=1.00]	-1.053	.251	17.606	1	.000	-1.544	561
	[DISTRICT=2.00]	2.733	.548	24.884	1	.000	1.659	3.806
	[DISTRICT=3.00]	150	.414	.131	1	.718	962	.662
	[DISTRICT=4.00]	20.763	.000	•	1	•	20.763	20.763
	[DISTRICT=5.00]	2.058	.392	27.584	1	.000	1.290	2.826
Location	[DISTRICT=6.00]	.961	.312	9.506	1	.002	.350	1.572
Location	[DISTRICT=7.00]	2.133	.318	44.891	1	.000	1.509	2.756
	[DISTRICT=8.00]	2.106	1.403	2.254	1	.133	643	4.856
	[DISTRICT=9.00]	1.457	.411	12.563	1	.000	.651	2.263
	[DISTRICT=10.00]	-1.240	.404	9.433	1	.002	-2.032	449
	[DISTRICT=11.00]	.900	.355	6.447	1	.011	.205	1.595
	[DISTRICT=12.00]	0	•		0		•	

Table 4.88 Sample Two: Test of parallel lines of ordinal logistic regression between

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	84.835			
General	70.087	14.748	11	.194

DISTRICT and SEVERITY

The model from the ordinal logistic regression for sample two is statistically significant. There is a significant relationship between DISTRICT and SEVERITY. The ordered logodds regression coefficients were obtained by comparing to DISTRICT=12. There are three districts (district one, three, and ten) behave better than district twelve with the interpretation as following:

- The log odds of being in a higher level of settlement severity will decrease by 1.053 if moving from the DISTRICT=12 TO DISTRICT=1,
- The log odds of being in a higher level of settlement severity will decrease by 0.150 if moving from the DISTRICT=12 TO DISTRICT=3,
- The log odds of being in a higher level of settlement severity will decrease by 1.240 if moving from the DISTRICT=12 TO DISTRICT=10.

4.10 Comprehensive Model

Based on the analyses between each parameter and dependent variable above, the dependent variable SEVERITY may not be ordinal in nature when analyzing the relationship between ADT and SEVERITY and the relationship between DISTRICT and SEVERITY. Consequently, both ordinal logistic regression and multinomial logistic regression were carried out to develop comprehensive models for two samples, and these two different methods were compared to determine which one is better.

The model structure is shown in Table 4.89. For categorical variables (factors) in ordinal or multinomial logistic regression, dummy variables created to represent an attribute with two or more distinct categories/levels should be defined to interpret the SPSS output. For each categorical variable with K levels, K-1 dummy variables should be assumed. Dummy variables in this study is defined in Table 4.90. According to different probability theory, output form of the models from ordinal logistic regression and multinomial logistic regression is different. Proportional-odds cumulative logit model is possibly the most popular model for ordinal data. This model uses cumulative probabilities upto a threshold, thereby making the whole range of ordinal categories binary at that threshold. The response Y in this study has three levels which are represented by 1, 2, and 3, and the associated probabilities are π_1 , π_2 , and π_3 . For ten independent variables, the following equations are supposed to be developed for ordinal logistic regression.

$$Logit \frac{\pi_1}{1-\pi_1} = Logit \frac{\pi_1}{\pi_2 + \pi_3} = -\alpha_1 + \beta_1 x_1 + \dots + \beta_{10} x_{10} \quad (4.12)$$

$$Logit \frac{\pi_1 + \pi_2}{1 - (\pi_1 + \pi_2)} = Logit \frac{\pi_1 + \pi_2}{\pi_3} = -\alpha_2 + \beta_1 x_1 + \dots + \beta_{10} x_{10} \quad (4.13)$$
$$\pi_1 + \pi_2 + \pi_3 = 1 \quad (4.14)$$

Therefore,

$$\pi_{1} = \frac{\exp(-\alpha_{1} + \beta_{1}x_{1} + \dots + \beta_{10}x_{10})}{1 + \exp(-\alpha_{1} + \beta_{1}x_{1} + \dots + \beta_{10}x_{10})} \quad (4.15)$$

$$\pi_{2} = \frac{\exp(-\alpha_{1} + \beta_{1}x_{1} + \dots + \beta_{10}x_{10})}{1 + \exp(-\alpha_{1} + \beta_{1}x_{1} + \dots + \beta_{10}x_{10})} - \pi_{1} \quad (4.16)$$

$$\pi_{3} = 1 - \pi_{1} - \pi_{2} \quad (4.17)$$

When the assumption states that the slope coefficients in the model are the same across response categories for ordinal logistic regression is rejected, a less restrictive model of multinomial logistic regression is an optimal method. Multinomial logistic regression models how multinomial response variable depends on a set of explanatory variables. The following equations, if Y = 3 is set as the referent, are supposed to be developed for multinomial logistic regression with ten independent variables. It is important to note that the parameter coefficients for different equations are different, which is the biggest difference of the output between the ordinal logistic regression and multinomial logistic regression.

$$Logit \frac{\pi_1}{\pi_3} = \alpha_1 + \beta_{11}x_1 + \dots + \beta_{110}x_{10} \quad (4.18)$$
$$Logit \frac{\pi_2}{\pi_3} = \alpha_2 + \beta_{21}x_1 + \dots + \beta_{210}x_{10} \quad (4.19)$$
$$\pi_1 + \pi_2 + \pi_3 = 1 \quad (4.20)$$

Covariates	Factors	Dependent
LENGTH	DISTRICT	SEVERITY
WIDTH	ABUT	
AGE	APPT	
ADT	FSC	
EH		
FSD		

Table 4.89 Classification of the variables in the model

DISTRICT			ABUT
Original	Dummy	Original	Dummy
District1=1;	DIS1=1, otherwise DIS1=0;	Perched=1;	ABUT1=1, otherwise ABUT1=0;
District2=2;	DIS2=1, otherwise DIS2=0;	Closed=2;	ABUT2=1, otherwise ABUT2=0;
District3=3;	DIS3=1, otherwise DIS3=0;	Spill-	All ABUT=0
District4=4;	DIS4=1, otherwise DIS4=0;	through=3	
District5=5;	DIS5=1, otherwise DIS5=0;		
District6=6;	DIS6=1, otherwise DIS6=0;		
District7=7;	DIS7=1, otherwise DIS7=0;		
District8=8;	DIS8=1, otherwise DIS8=0;		
District9=9;	DIS9=1, otherwise DIS9=0;		
District10=10;	DIS10=1, otherwise DIS10=0;		
District11=11;	DIS11=1, otherwise DIS11=0;		
District11=12	All DIS=0		

	APPT		FSC
Original	Dummy	Original	Dummy
Flexible=1;	APPT1=1, otherwise APPT1=0;	Soft=1;	FSC1=1, otherwise FSC1=0;
Rigid=2	All APPT=0	Stiff=2;	FSC2=1, otherwise FSC2=0;
		Very stiff=3;	FSC3=1, otherwise FSC3=0;
		Hard=4	All FSC=0

4.10.1 Sample One

An ordinal regression considering all predictors for prediction of approach settlement levels based on project characteristics was carried out. Some important model information are shown in Table 4.91 ~ Table 4.94, and the complete output for this ordinal logistic regression is shown in Appendix E. From the model fitting information table, p-value of this model is 0.056. If an alpha 0.05 is set, the assumption that all regression coefficients of predictors are zero cannot be violated and this model is not better than a null model (without any predictors). In other words, this comprehensive model cannot fit the relationship between all predictors and settlement levels well. The goodness of fit table presents two tests, Pearson and Deviance, of the null hypothesis that the model adequately fits the data. If the significance value is small (less than 0.05), then the model does not adequately fit the data. In this case, its value is greater than 0.05, so the data are consistent with the model assumptions.

From the table of pseudo R-square, there are three pseudo R-squared values computed by three different methods. Logistic regression does not have an equivalent to the R-squared that is found in ordinary least squares (OLS) regression. OLS is concerned with the squares of the errors. It tries to find a fitting line going through the sample data that

minimizes the sum of the squared errors; however, many people have tried to come up with one. There are a wide variety of pseudo R-squared statistics which can give contradictory conclusions. Because these statistics do not mean what R-squared means in OLS regression (the proportion of variance of the response variable explained by the predictors). Generally, these pseudo r-square values are not very high either not very low, it is suggested interpreting them with great caution. The test of parallel lines indicates that the proportional odds assumption is not violated and the method of ordinal regression for identifying the relationship between approach settlement and its causative factors is applicable. However, the model fitting information indicates that this model may not be better than a null model. Therefore, method of multinomial logistic regression was adopted.

Table 4.91 Sample One: Model fitting information of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	177.953			
Final	147.035	30.918	20	.056

Table 4.92 Sample One: Goodness of fit of ordinal logistic regression

	Chi-Square	df	Sig.
Pearson	154.849	152	.421
Deviance	147.035	152	.599

Table 4.93 Sample One: Pseudo R-square of ordinal logistic regression

Method	Value
Cox and Snell	.299
Nagelkerke	.344
McFadden	.174

Table 4.94 Sample One: Test of parallel lines of ordinal logistic regression

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	147.035			
General	116.451 ^b	30.584 ^c	20	.061

Another method of multinomial logistic regression was carried out aiming at developing a more accurate and parsimonious model. The complete output for this multinomial logistic regression is shown in Appendix F. The model fitting information of multinomial logistic regression shows that the p-value of model fitting information is smaller than 0.05, which means this model can fit the relationship between SEVERITY and all independent variables well. The goodness of fit table shows that the significance values from Pearson and Deviance tests are much higher than 0.05 and bigger than the results from ordinal logistic regression, which means this model adequately fits the data. The values of pseudo R-square are not very high or not very low. The likelihood ratio tests indicate AGE, DISTRICT, and FSD are statistically significant for this model. The interpretation of the parameter estimates is presented as following:

Minimal relative to Severe:

- AGE: If an approach was to increase AGE by one year, the multinomial log-odds of being minimal relative to severe would be expected to increase by 0.131 unit while holding all other variables in the model constant.
- DISTRICT: If a bridge was moved to district one from district twelve, the multinomial log-odds of being minimal relative to severe would be expected to increase by 21.483 unit while holding all other variables in the model constant. The estimated multinomial logistic regression coefficients for other districts can be interpreted in the same way.
- FSD: If the foundation soil depth for a bridge was to increase by one feet, the multinomial log odds of being minimal relative to severe would be expected to decrease by 0.175 unit while holding all other variables in the model constant.

Moderate relative to Severe:

- AGE: If an approach was to increase AGE by one year, the multinomial log-odds of being moderate relative to severe would be expected to increase by 0.014 unit while holding all other variables in the model constant.
- DISTRICT: If a bridge was moved to district one from district twelve, the multinomial log-odds of being moderate relative to severe would be expected to increase by 18.093 unit while holding all other variables in the model constant. The estimated multinomial logistic regression coefficients for other districts can be interpreted in the same way.
- FSD: If the foundation soil depth for a bridge was to increase by one feet, the multinomial log odds of being minimal relative to severe would be expected to decrease by 0.004 unit while holding all other variables in the model constant.

The probability that each settlement level may occur can be expressed in the following equations:

$$logit \frac{\pi_1}{\pi_3} = 11.246 + 0.003LENGTH - 0.013WIDTH + 0.131AGE + 0.000ADT - 0.084EH - 0.175FSD + 21.483DIS1 + 0.000DIS2 + 0.000DIS3 + 1.767DIS4 + 3.722DIS5 + 17.908DIS6 + 1.751DIS7 + 0.000DIS8 + 4.132DIS9 + 24.518DIS10 + 20.706DIS11 + 0.000DIS12 - 37.279ABUT1 - 16.258ABUT2 + 0.000ABUT3 - 1.622APPT1 + 0.000APPT2 - 32.712FSC1 - 29.828FSC2 - 30.989FSC3 + 0.000FSC4 (4.21)$$

$$logit \frac{\pi_2}{\pi_3} = -4.972 + 0.000LENGTH + 0.021WIDTH + 0.014AGE$$

+ 0.000ADT - 0.016EH - 0.004FSD + 18.093DIS1
+ 0.000DIS2 + 0.000DIS3 + 16.967DIS4 + 19.462DIS5
+ 16.612DIS6 + 17.134DIS7 + 0.000DIS8 + 17.776DIS9
+ 17.041DIS10 + 16.859DIS11 + 0.000DIS12
- 13.840ABUT1 - 0.075ABUT2 + 0.000ABUT3
+ 0.898APPT1 + 0.000APPT2 - 13.082FSC1
- 14.185FSC2 - 13.552FSC3 + 0.000FSC4 (4.22)

The probability relationship between three severity levels:

$$\pi_1 + \pi_2 + \pi_3 = 1 \quad (4.23)$$

By using these equations above, it is able to compute the probability that each settlement category may occur based on all predictors. The settlement category with the largest

probability will be selected as the predicted category. The classification table shows the predicted accuracy for each settlement level. The overall percentage of correct of predicting the settlement levels is 67.8%.

Model	Model Fitting Criteria	Likelihood Ratio Tests		Tests
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	177.953			
Final	115.383	62.570	40	.013

 Table 4.95 Sample One: Model fitting information of multinomial logistic regression

Table 4.96 Sample One:	Goodness of fit of or	rdinal logistic regression
1		0 0

	Chi-Square	df	Sig.
Pearson	120.916	132	.746
Deviance	115.383	132	.848

 Table 4.97 Sample One: Pseudo R-square of multinomial logistic regression

Method	Value
Cox and Snell	.513
Nagelkerke	.589
McFadden	.352

	Model Fitting Criteria	Likelihood Ratio Tests		sts
Effect	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	115.383	.000	0	
LENGTH	117.334	1.950	2	.377
WIDTH	116.110	.727	2	.695
AGE	129.661	14.278	2	.001
ADT	117.052	1.669	2	.434
EH	117.560	2.176	2	.337
FSD	121.448	6.065	2	.048
DISTRICT	152.321	36.938	16	.002
ABUT	120.157	4.773	4	.311
APPT	118.496	3.113	2	.211
FSC	119.905	4.521	6	.606

 Table 4.98 Sample One: Likelihood ration tests of multinomial logistic regression

	Predicted				
Observed	1.00	2.00	3.00	Percent Correct	
1.00	11	1	2	78.6%	
2.00	2	22	12	61.1%	
3.00	3	8	26	70.3%	
Overall Percentage	18.4%	35.6%	46.0%	67.8%	

 Table 4.99 Sample One: Classification table of multinomial logistic regression

With the purpose of better interpretation of the parameter estimates, the variation trends of the predicted probability of minimal versus the statistically significant predictors (AGE, DISTRICT, and FSD) were identified. From the variation trend of the estimated probability of minimal versus approach age, the probability of being in the settlement level of minimal will increase as approach age increases. From the variation trend of the estimated probability of minimal versus transportation districts, district one, ten, and eleven show a higher probability of being in the settlement level of minimal than other districts. Similarly, the variation trend of the estimated probability of minimal versus foundation soil depth indicates that the probability of being in the settlement level of minimal will increase at first as the foundation soil depth increase by 25 feet and then decrease as the foundation soil depth continues to increase.



Footnote: interpolation line stands for variation trend at total

Figure 4.29 Sample One: Variation trend of the estimated probability of minimal

versus approach age



Footnote: interpolation line stands for variation trend at total

Figure 4.30 Sample One: Variation trend of the estimated probability of minimal versus transportation districts



Footnote: interpolation line stands for variation trend at total

Figure 4.31 Sample One: Variation trend of the estimated probability of minimal versus foundation soil depth

From the interpretation of the parameter estimates for significant predictors and the variation trends of the predicted probability of minimal versus the statistically significant predictors, the following conclusions can be concluded:

- As age of an approach increases, the probability of being in a higher settlement level will decrease.
- The performance of approaches in the district one, district ten, and district eleven behaves better than other districts.

• As foundation soil depth for a bridge increases, the probability of being in a higher settlement level will decrease.

4.10.2 Sample Two

Both ordinal and multinomial logistic regressions were carried out for sample two, and their results are similar. Both models are applicable and reliable for this sample, and the same conclusions were obtained. The outputs of ordinal logistic regression and multinomial logistic regression for sample two are shown in Appendix G and Appendix H, respectively. Method of multinomial logistic regression is solely illustrated in this section in order to make it easier to compare with sample one. Some important model fitting information for this multinomial logistic regression are shown in Table 4.100 \sim Table 4.104, This model is better than a null model from the model fitting information, which implies that at least one parameter estimate is not zero. From the table of goodness of fit, the null hypothesis that the model adequately fits the data is true due to the high significance values from Pearson and Deviance tests. In other words, this model is able to fit the relationship between all predictors and SEVERITY well. From the table of likelihood ratio tests, DISTRICT, AGE, ADT, and APPT are statistically significant, while the others are not. The interpretation of the parameter estimates is summarized as following:

Minimal relative to Severe:

• DISTRICT: If a bridge was moved to district one from district twelve, the multinomial log-odds of being minimal relative to severe would be expected to increase by 2.278 while holding all other variables in the model constant. The

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estimated multinomial logistic regression coefficients for other districts can be interpreted in the same way.

- AGE: If an approach was to increase AGE by one year, the multinomial log-odds of being minimal relative to severe would be expected to decrease by 0.029 while holding all other variables in the model constant.
- ADT: If the ADT for an approach was to increase by one unit, the multinomial log odds of being minimal relative to severe would be expected to increase by 1.0E-8 while holding all other variables in the model constant.
- APPT: If a bridge approach was changed to flexible from rigid, the multinomial log-odds of being minimal relative to severe would be expected to decrease by 0.977 while holding all other variables in the model constant.

Moderate relative to Severe:

- DISTRICT: If a bridge was moved to district one from district twelve, the multinomial log-odds of being moderate relative to severe would be expected to increase by 1.549 while holding all other variables in the model constant. The results from ordinal logistic regression also concludes that the log odds of being in a higher level of settlement severity will decrease by 1.124 if moving from the district twelve to district one while the other variables in the model are held constant.
- AGE: If an approach was to increase AGE by one year, the multinomial log-odds of being moderate relative to severe would be expected to decrease by 0.009 while holding all other variables in the model constant. The ordinal logistic regression indicates: for a one unit increase in AGE on the expected SEVERITY

level given the other variables are held constant in the model, the ordered logodds of being in a higher level of SEVERITY will increase by 0.017.

- ADT: If the ADT for an approach was to increase by one unit, the multinomial log odds of being moderate relative to severe would be expected to increase by 1.2E-8 unit while holding all other variables in the model constant. The parameter estimates from multinomial logistic regression show that the coefficient for ADT is approximately equal to zero due to a very small value. However, the ordinal logistic regression concludes that the ordered log-odds of being in a higher level of SEVERITY will increase by 1.910E-5 if increasing one unit in ADT on the expected SEVERITY level given the other variables are held constant in the model,.
- APPT: If a bridge approach was changed to flexible from rigid, the multinomial log-odds of being moderate relative to severe would be expected to decrease by 0.525 while holding all other variables in the model constant. Similarly, the ordinal logistic regression concludes that the log odds of being in a higher level of settlement severity will increase by 0.529 if changing from the rigid approach to flexible approach while the other variables in the model are held constant.

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Table 4.100 Sample Two: Model fitting information of multinomial logistic

regression

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1270.242			
Final	984.788	285.453	46	.000

Table 4.101 Sample Two: Goodness of fit of multinomial logistic regression

	Chi-Square	df	Sig.
Pearson	1128.538	1150	.669
Deviance	984.788	1150	1.000

Table 4.102 Sample Two:: Pseudo R-square of multinomial logistic regression

Methods	Value		
Cox and Snell	.379		
Nagelkerke	.430		
McFadden	.225		

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	984.788	.000	0	•
LENGTH	987.497	2.709	2	.258
WIDTH	988.640	3.852	2	.146
AGE	999.009	14.220	2	.001
ADT	994.452	9.664	2	.008
EH	984.984	.196	2	.907
FSD	986.155	1.367	2	.505
DISTRICT	1169.284	184.496	22	.000
ABUT	988.706	3.917	4	.417
APPT	991.444	6.655	2	.036
FSC	987.878	3.089	6	.798

 Table 4.103 Sample Two: Likelihood ratio tests of multinomial logistic regression

 Table 4.104 Sample Two: Classification table of multinomial logistic regression

	Predicted				
Observed	1.00	2.00	3.00	Percent Correct	
1.00	122	62	8	63.5%	
2.00	70	168	35	61.5%	
3.00	8	54	73	54.1%	
Overall Percentage	33.3%	47.3%	19.3%	60.5%	
The probability that each settlement level may occur can be expressed in the following equations:

$$logit \frac{\pi_1}{\pi_3} = 4.624 - 0.001LENGTH - 0.015WIDTH - 0.29AGE + 1.0 \times 10^{-8}ADT$$

- 0.006EH - 0.003FSD + 2.278DIS1 - 18.812DIS2 + 0.452DIS3
- 20.848DIS4 - 3.749DIS5 - 0.980DIS6 - 2.714DIS7 - 17.614DIS8
- 2.427DIS9 + 16.495DIS10 - 1.356DIS11 + 0.000DIS12
- 0.749ABUT1 - 1.246ABUT2 + 0.000ABUT3 - 0.977APPT1
+ 0.000APPT2 - 0.188FSC1 - 0.718FSC2 - 1.026FSC3
+ 0.000FSC4 (4.24)

$$logit \frac{\pi_2}{\pi_3} = 2.423 + 0.000LENGTH + 0.002WIDTH - 0.009AGE + 1.2 \times 10^{-8}ADT$$

- 0.005EH + 0.007FSD + 1.549DIS1 - 1.907DIS2 + 0.176DIS3
- 20.103DIS4 - 0.969DIS5 - 0.140DIS6 - 1.580DIS7 - 1.072DIS8
- 0.830DIS9 + 15.721DIS10 + 0.193DIS11 + 0.000DIS12
- 0.319ABUT1 - 0.082ABUT2 + 0.000ABUT3 - 0.525APPT1
+ 0.000APPT2 - 0.383FSC1 - 0.662FSC2 - 0.846FSC3
+ 0.000FSC4 (4.25)

The probability relationship between three severity levels:

$$\pi_1 + \pi_2 + \pi_3 = 1 \tag{4.26}$$

By using these three equations above, it is able to compute the probability that each settlement category may occur based on all predictors. The settlement category with the largest probability will be selected as the predicted category. The classification table

shows the predicted accuracy for each settlement level. The overall percentage of correct of predicting the settlement levels by using this model is 60.5%.

As the same way of dealing with sample one, the variation trends of the predicted probability of minimal versus the statistically significant predictors (DISTRICT, AGE, ADT, and APPT) were identified for sample two. From the variation trend of the estimated probability of minimal versus transportation districts, district one, three, and ten show a higher probability of being in the settlement level of minimal than other districts. From the variation trend of the estimated probability of minimal versus approach age, the probability of being in the settlement level of minimal will decrease as approach age increases. Similarly, the variation trend of the estimated probability of minimal versus average daily traffic indicates that the probability of being in the settlement level of minimal will decrease as the average daily traffic increase. Furthermore, it is distinct to conclude that rigid approaches tend to have a higher probability of experiencing settlement levels of minimal than flexible approaches.



Footnote:interpolation line stands for variation trend at total

Figure 4.32 Sample Two: Variation trend of the estimated probability of minimal

versus transportation districts



Footnote: interpolation line stands for variation trend at total

Figure 4.33 Sample Two: Variation trend of the estimated probability of minimal

versus approach age



Footnote: interpolation line stands for variation trend at total

Figure 4.34 Sample Two: Variation trend of the estimated probability of minimal

versus average daily traffic



Footnote: interpolation line stands for variation trend at total

Figure 4.35 Sample Two: Variation trend of the estimated probability of minimal versus average approach type

From the interpretation of the parameter estimates for significant predictors and the variation trends of the predicted probability of minimal versus the statistically significant predictors, the following conclusions can be concluded:

- The performance of approaches in the district one, district three, and district ten behaves better than other districts.
- As age of an approach increases, the probability of being in a higher settlement level will increase.

- As average daily traffic for an approach increases, the probability of being in a higher settlement level will increase.
- Flexible approaches tend to have a higher probability of being in a higher settlement level than rigid approaches.

4.10.3 Comparison between Two Models

The process of applying a predictive model to a set of data is referred to as scoring the data. SPSS has procedures for building predictive models of logistic regressions. Once a model has been built, the model specifications can be saved in a file that contains all of the information necessary to reconstruct the model. Then the model file can be used to generate predictive scores in other datasets. This section used the utility named Scoring Wizard in SPSS to apply the model created with sample one to dataset of sample two and generate predicted settlement category, and vice versa apply the model created with sample two to dataset of sample one. The scoring process consists of three basic steps:

- Build the model and save the model file. A predictive model can be built by using a dataset for which the outcome of interest is known. For example, if a model that will predict the settlement levels for sample one is aimed to be developed, a dataset that already contains information on observed settlement levels is supposed to be possessed.
- 2. Apply that model to a different dataset to obtain predicted outcomes. For example, apply the model created from sample one to data of sample two, it needs to assume that the outcome of settlement levels for sample two is not known.
- 3. Finally, compare the predicted settlement category with the observed settlement category and obtain the accuracy rate for both models.

The comparison between the observed settlement category and the predicted settlement category is shown in Table 4.105. When applying the model created with sample one to dataset of sample two, the accuracy rate of predicting the right settlement category is 30.2%. Conversely, when applying the model created with sample two to dataset of sample one, the accuracy rate of predicting the right settlement category is 28.7%. Both accuracy rates are slightly lower than a stochastic probability of 33% that could be obtained by guessing the settlement category randomly. This is not surprising because it demonstrates these two models are different models that are developed from different samples based on different selection criterions. The users can decide which one to use by different requirements and purposes.

Category	Percent Correct	
Apply model one to	30.2%	
data of sample two		
Apply model two to	28.7%	
data of sample one	20.170	

Table 4.105 Percent correct of applying two model to each other dataset

In logistic regressions, the count data (i.e., LENGTH and ADT) with a considerable variability are processed as continuous variables while they are not truly continuous. A check for empty or small cells by doing a crosstab between categorical independent variables and the outcome variable was conducted and shows that there are more than 65% cells (i.e., dependent variable levels by observed combinations of predictor variable values) with zero frequencies for both samples. If a cell has very few cases, the model may become unstable or it might not run at all. The size of sample two is much bigger

than sample one. In this instance, models developed from sample one may not be stable even if the model could gain a satisfied p-value.

4.10.4 Conclusions

The model developed from the method of ordinal logistic regression for sample one is found not statistically significant. In other words, this model is not better than a null model and cannot fit the relationship between settlement levels and all predictors well. Then a multinomial logistic regression was conducted on sample one. The results show that AGE, DISTRICT, and FSD are statistically significant while the others are not. This model indicates that there is a negative correlation between AGE and SEVERITY, which means the probability of being in a higher settlement level will decrease as the approach age increases. This conclusion is contrary to the relationship between AGE and SEVERITY of sample two. This reverse can be explained by the fact that a selection bias may be formed because the bridges with severe bump usually impress respondents most. Sample one shows that district one, district ten, and district eleven behave better than other districts in the treatment of differential settlement at bridge ends. In addition, the probability of being in a higher settlement level will decrease as foundation soil depth for a bridge increases.

Both ordinal and multinomial logistic regressions were implemented for sample two, and both methods yield the similar results. Both logistic regressions of sample two reveal that DISTRICT, AGE, ADT, and APPT are statistically significant for the relationship between the settlement severity and its causative predictors. District one, district three, and district ten behave better by comparing to other districts in the treatment of differential settlement at bridge ends. There is a positive correlation between AGE and

SEVERITY, which implies that the probability of being in a higher level of approach settlement will increase as the bridge age increases while holding all other predictors constant. As average daily traffic for an approach increases, the probability of being in a higher settlement level will increase. Furthermore, flexible approaches tend to have a higher probability of being in a higher settlement level than rigid approaches.

5 DISTIRCT INTERVIEWS

The research team visited five out of twelve districts to document various problems that are reported by local bridge personnel at bridge approaches. Bridge engineers in design, construction, and maintenance from district one, district three, district five, district eleven, and district twelve were interviewed in type of face to face or video conferences. This section is a summary of current practices that have been adopted for mitigating settlements at bridge approaches, as well as suggested methods or measures for managing bridge approaches which may produce potential settlements based on the results of predictive models. These current practices and suggestions are listed based on various groups of treatments such as foundation soil, backfill materials, approach slab, abutments, and drainage.

The major purpose of this chapter is to provide bridge engineers the prescriptive correction measures that could be applied to predicted differential settlement. On the one hand, the bridge designers could use the models developed in Chapter four to predict the approach settlement level based on foundation, approach, embankment, and other bridge characteristics for a new bridge. And then apply corresponding techniques or measures to prevent or minimize the settlement problems that may occur in the future. On the other hand, the bridge maintenance engineers also could use the models to predict approach settlement level for a bridge that has been constructed. And then implement maintenance measures for different levels of distressed approaches.

5.1 Foundation Soil

Foundation soils beneath the embankment and embankment fill is one of the important factors that influence the performance of bridge approaches (Wahls, 1990). Many studies have demonstrated that the settlement mechanism and process are different between soil of granular material type and soil of cohesive material type. For granular soils, such as sand, gravel, and rock, it doesn't need to undergo long term settlements, and the differential settlement between roadway and bridge upper structure can be negligible. While for cohesive soils, the settlement process is much longer than granular soils. Large settlements either from primary and/or secondary consolidation settlement may be formed in a long term. Subsequently, the settlements of the foundation soils and embankment fill may lead to a poor performance of bridge approaches. Generally, the time period for the primary phase can range from a few months in very granular soils to seven to ten years for some clays (Hopkins, 1973). Hence different mitigation methods are supposed to be adopted to deal with these two different type of foundation soils.

Both predictive models developed from sample one and sample two show that there is no significant association between foundation soils and approach settlement levels. It does not equal to a deduction that the foundation soils cannot able to influence the approach settlement. However, it should be noted that the foundation soils information that was used to develop the models are foundation soils after improvement or special treatments, especially for highly compressible foundation soils. Appropriate treatment methods or measures for highly compressible foundation soils are necessary before the construction of the construction of bridge parts. Therefore, a full investigation about the foundation soils is needed prior to design and construction. After the literature review and interviews

with the local bridge engineers in these five districts, Table 5.1 summarizes the improvement/treatment techniques or measures for foundation soils in different soil types. According to the function of each stabilization technique, Puppala (2009) divided these techniques into three subcategories as shown in Table 5.2.

Technique	Granular soils	Cohesive soils
Excavation and replacement	X	✓
Preloading with or without surcharge	\checkmark	\checkmark
Dynamic compaction	\checkmark	\checkmark
Grouting	\checkmark	\checkmark
Drains	×	\checkmark
Grave/Stone columns	×	\checkmark
Geosynthetics	\checkmark	\checkmark

Table 5.1 Summary of foundation soils improvement methods based on soil type

Table 5.2 Summary of foundation soils improvement methods based on soil type

Mechanical	Hydraulic	Reinforcement
Mechanical Excavation and replacement; Preloading and surcharge; Dynamic compaction	Hydraulic Sand drains; Prefabricated drains; Surcharge loading	ReinforcementColumns:Stone and lime columns;Geopiers;Concrete injected columns;Deep soil mixing columnsDeep foundations:In-situ compacted piles;CFA piles;Driven pilesGeosynthetics:
Preloading and surcharge; Dynamic compaction	Surcharge loading	In-situ compacted piles; CFA piles; Driven piles
		Geosynthetics: Geotexitiles/Geogrids; Geocells

based on the function (Puppala, 2009)

The current practices regrading foundation preparation are summarized by interviewing local bridge engineers. The following conclusions can be obtained:

- Most bridge design engineers consider that a reliable subsurface exploration information for a selected site is paramount. The importance of foundation exploration phase cannot be overemphasized. Responsible geotechnical personnel must be assigned with this task.
- 2. Several ground improvement methods are usually adopted as a combination to guarantee an adequate foundation for new bridges. The most common ways that have been using to improve highly compressible foundation soils are preloading the foundation soils and excavation and replacement. Some DOTs, such as Iowa

DOT and TxDOY, have implemented guidelines on foundation soils treatment. However, the KYTC has not given a manual that will guide designers and constructors how to carry out different ground improvement methods for a particular field situation.

- 3. The process of preloading and precompression the foundation soils usually spans a long time period. Many districts reported that they are not willing to accommodate the preloading and/or precompression periods since this process may lead to construction delay and drive initial construction costs higher.
- 4. Using the predictive models, if the approach settlement for a constructed bridge was classified as severe due to the problem of foundation soils. Two easy and reliable alternatives are proposed when situations do arise that the foundation soils are not adequate. One is to reduce the loads applied to the foundation, and the other method is to improve the properties of the foundation soil by grouting chemical.

5.2 Embankment Backfill Material

Consensus of opinion that high quality granular engineered fill would influence the serviceability of the embankment, in the aspects of slope stability, compression, consolidation, or bearing capacity issues, has been reached. White et al. (2005) suggested that the embankment fill material should have these following properties:

- being easily compacted,
- not time-dependent,
- not sensitive to moisture,
- providing good drainage,

- erosion resistance, and
- shear resistance.

Hoppe (1999) summarized the embankment material specifications and lift thickness and percent compaction requirements from various DOTs as shown in Table 5.3 and Table 5.4, respectively.

State	Same/Different from regular embankment	% passing 75mm (No. 200 sieve)	Miscellaneous
AL	Same		A-1 to A-7
AZ	Different		
CA		<4	Compacted pervious material
СТ	Different	<5	Pervious material
DE	Different		Borrow type C
FL	Same		A-1, A-2-4 through A-2-7, A-4, A-5, A-6,
			A-7 (LL<50)
GA	Same		GA Class I, II or III
ID			A yielding material
IL	Different		Porous, granular
IN	Different	<8	
IO	Different		Granular; can use Geogrid
KS			Can use granular, flowable or light
N D			weight
KY		<10	Granular
LA			Granular
ME	Different	<20	Granular borrow
MA	Different	<10	Gravel borrow type B, M1.03.0

 Table 5.3 Embankment material specifications (Hoppe, 1999)

			Only top 0.9 m (3 ft) are different
MI	Different	<7	(granular material
			Class II)
MN		<10	Fairly clean granular
MO			Approved material
MS	Different		Sandy or loamy, non-plastic
MT	Different	<4	Pervious
NE			Granular
NV	Different		Granular
NH	Same	<12	
NJ	Different	<8	Porous fill (Soil Aggregate I-9)
NM	Same		
NY		<15	<30% Magnesium Sulfate loss
ND	Different		Graded mix of gravel and sand
OH	Same		Can use granular material
OK	Different		Granular just next to backwall
OR	Different		Better material
SC	Same		
SD	Varies		Different for integral; same for
50	v unes		conventional
TX	Same		
VT	Same		Granular
VA	Same		Pervious backfill
WA			Gravel borrow
WI	Different	<15	Granular
WY	Different		Fabric reinforced

	Lift	%	
State	mm(inch)	Compaction	Miscellaneous
AL	203(8)	95	
AZ	203(8)	100	
CA	203(8)	95	For top 0.76 m (2.5 ft)
СТ	152(6)	100	Compacted lift indicated
DE	203(8)	95	
FL	203(8)	100	
GA		100	
ID	203(8)	95	
IL	203(8)	95	For top, remainder varies with embankment
	(.)		height
IN	203(8)	95	
ΙΟ	203(8)	None	One roller pass per inch thickness
KS	203(8)	90	
KV	152(6)	05	Compacted lift indicated; Moisture =
K I	132(0)	95	+2% or -4% of optimum
LA	305(12)	95	
ME	203(8)		At or near optimum moisture
MD	152(6)	97	For top 0.30 m (1ft), remainder is 92%
MA	152(6)	95	
MI	230(9)	95	
MN	203(8)	95	
MO	203(8)	95	
MS	203(8)		
MT	152(6)	95	At or near optimum moisture
NE		95	

 Table 5.4 Lift thickness and percent compaction requirements (Hoppe, 1999)

NV		95	
NH	305(12)	98	
NJ	305(12)	95	
NY	152(6)	95	Compacted lift indicated
ND	152(6)		
OH	152(6)		
OK	152(6)	95	
OR	203(8)	95	For top 0.91 m (3ft), remainder is 90%
SC	203(8)	95	
SD	203-305(8-12)	97	0.20 m (8 inch) for embankment, 0.30 m (12 inch) for bridge end backfill
TX	205(12)	NT	
TX	305(12)	None	
VT	203(8)	90	
VA	203(8)	95	+ or – 20% of optimum moisture
WA	102(4)	95	Top 0.61 m (2 ft), remainder is 0.20 m (8 inch)
WI	203(8)	95	Top 1.82 m (6 ft and within 60 m (200 ft), remainder is 90%
WY	305(12)		Use reinforced geotextiles layers

From the table of embankment material specifications, 49 percent of the DOTs use more rigorous material specifications for an approach fill than for a regular highway embankment fill. From Table 5.4, it can be drawn that a 95 percent of the standard proctor test compaction condition is generally specified for the compaction of approach fill. Since the embankment must provide a smooth transition between the roadway and the bridge, KYTC Structural Design Manual specifies the standards for design and construction considerations both in materials quality requirements and compaction specifications on the title sheet: Special Provision 69, "Embankment at Bridge End Bent

Structures," and Standard Drawings RGX-100 and RGX-105, "Treatment of Embankment at Bridge End-Bent Structures." In Kentucky, granular embankment is usually adopted except that special construction methods are specified when granular embankment materials are erodible or unstable.

Apart from the selection of embankment backfill material, precompression technique in embankment construction is cited by most bridge engineers in interviews as one of another important methods to minimize potential of settlement and lateral movement development in the approach embankments. The precompression in embankment construction is a process in which the weight of embankment will be considered as a load inducing the consolidation settlement and completing the process prior to the beginning of actual pavement or roadway construction (Puppala, 2009). Similar with the precompression method for foundation soils, this method may lead to delay, even up to one year, in most of the cases. Hence a reasonable schedule considering this step/process is necessary so as to allow embankment settlement prior to roadway construction before the placement of approach pavement (Cotton et al., 1987).

Another effective way, cited most by districts, of solving the excessive approach settlement is the use of flowable fills. The flowable fill has other common names, such as unshrinkable fill, controlled density fill, flowable mortar, flowable fill, plastic soilcement, and soil-cement slurry (Du et al., 2006). Flowable fill is a low-strength mixing concrete used as a backfill behind the abutment wall to reduce the possibility of approach settlements near the surface, resulting from the compression of the backfill itself (Abu-Hejleh et al., 2006). Folliard et al. (2008) pointed out that the fluidity of flowable fill makes it a rapid and efficient backfilling material. This material could fill voids without

the need of any compaction, thus making the embankment as a whole uncompressible. The low-strength mixing concrete has been used by several districts in Kentucky and showed a good performance of preventing erosion of the backfill and enhancing the constructability of the fill behind the walls and its surrounding areas. Another advantage of this method is time-consuming (Snethen and Benson, 1998). This method is greatly appropriate for the bridge projects with urgent construction schedules. The interviewees also stated that this method is an expensive construction practice. In certain field and construction scenarios, the use of this practice would drive a higher construction cost. However, the benefits obtained by less approach settlement problems can balance the increased construction cost. Although flowable fill are widely used in Kentucky, no material requirements have been specified by KYTC. Various districts usually employ this method based on their experience. Colorado DOT provides exact specifications, on the material requirements for flowable fill. It stipulates the maximum lift thickness for flowable fill material is 3 ft and a placement of additional layers is not permitted until the flowable fill has lost sufficient moisture to be walked on without indenting more than 2 inches. Additionally Colorado DOT specifies that the flowable fill does not need any vibration because the vibration may stiffen the flowable fill by allowing the setting to occur faster in the field. The material requirements for flowable fill by Colorado DOT is shown in Table 5.5 as a reference for Kentucky use. In Iowa, the flowable fill has been frequently used as a placement under the existing bridges. Smadi (2001) suggested a flowable mortar that could be easily applied due to several advantages: fluidity, durability, less frequent maintenance, and easy excavation. Details of flowable mortar that are used by Iowa DOT are illustrated in Figure 5.1.

Ingredient	Lb/C.Y.
Cement	50
Water	325 (or as needed)
Coarse aggregate (AASHTO No.57 or 67)	1700
Fine aggregate (AASHTO M6)	1845

Table 5.5 Material requirements for flowable fill by Colorado DOT



Concrete pipe section at centerline

Note: Illustration is not to scale.

Figure 5.1 The flowable mortar used under a roadway pavement (Smadi, 2001)

When the predictive models are used to evaluate the approach settlement for a new bridge as severe, a type of technique or a combination of backfill selection, precompression technique, and flowable fills can be employed to solve the problem of the excessive settlements induced by the embankment. If the predicted approach settlement for an existing bridge is severe, the technique of flowable fill is also an effective way of solving the excessive approach settlement that has been demonstrated by different districts. A manual on flowable fill design and construction is supposed to be developed by KYTC to guide the employment of flowable fill.

5.3 Approach Slab

The use of approach slabs is one of the most popular approach settlement abatement techniques. The bridge approach slab is a part of a bridge that rests on the abutment at one end and on the embankment or a sleeper slab on the other end (Wahls, 1990). The problem with approach slabs is that the voids beneath the approach slab are formed when approach settlement occurs. If the slab is not designed with enough reinforcement to support the unsupported span length, cracking or complete failures may lead to the approach impassable to traffic (Dupont and Allen, 2002).

A survey on over 131 bridges in Texas conducted by James et al. (1991) found that the bridges with flexible pavement had a smoother transition than those with rigid pavement. Another survey based on bridges in South Carolina (Pierce at al., 2001) showed that the approach slab with asphalt overlays tend to increase surface roughness. Most state agencies specify that the use of approach slabs is only an option, not required as a must. Although approach slabs are widely used nationwide, some state agencies (Kentucky and Marryland) argue that the use of approach slabs cannot minimize the approach settlement that will finally develop while increase the construction cost. Although, the use of approach slabs is an expensive construction practice, the analysis in chapter four indicates that the use of approach slabs is still a practical alternative in certain field and construction scenarios where the use of such practice justifies the higher costs.

The results from the Chi-square tests and the effective ratio prove that the approach slab use has a positive impact on alleviating bump issues caused by differential settlement. However, it does not equal that a bump caused by differential settlement could be eliminated by using approach slabs, and approach slabs should be adopted to every bridge by DOTs. Since the bump problem caused by differential settlement is the responsibility of DOTs, which operate under a certain budget, the cost of any methods for eliminating or minimizing this problem is a significant factor. Many solutions to this problem from design, construction, and maintenance have been proposed by DOTs, however, the total cost of approach slab and its life-cycle maintenance must not exceed the total cost of flexible approach and its life-cycle maintenance. A new approach slab is usually designed to last longer than 20 years with a cost range from \$5,000 to \$10,000 (Dupont and Allen, 2002), which is much more expensive than a flexible approach; while no statistics have demonstrated that the life-cycle maintenance of an approach slab is much lower than maintenance cost of a flexible approach during its service life. If a regular asphalt wedge tapering the gradient change to return a smooth transition cannot fix an improper approach slab, replacement of the slab is required. Dupont and Allen (2002) also concluded that the replacement of an approach slab may have a cost over \$10,000.

In an effort to figure out the low usage rate of approach slabs in Kentucky, district interviews with local bridge engineers and maintenance personnel from five districts (one, three, five, eleven, and twelve) were conducted. The feedback is summarized as:

- KYTC specifies the use of approach slabs as directed by the project manager.
- Approach slab use varies dramatically among districts. District three and five have used approach slabs as a prevention technique for minimizing deferential

settlement, while the other three districts lag behind. Besides approach slabs, sleep slabs are usually placed transversally under approach slabs to disperse the load transmitted to the embankment. Good performance of approach slabs has been perceived in district three. District five indicated that approach slabs were used for most bridges two decades ago, but no distinct effect had been detected and slab use was abandoned due to high cost.

- The performance of the approach slabs depends on a series of factors including approach slab dimensions, steel reinforcement, use of a sleeper slab, and type of connection between the approach slab and the bridge. The mechanism that affects the performance of approach slabs is complex, and no specific manuals for approach slab have been established in Kentucky to specify some design or construction issues, such as joint, length, vertical place, reinforcement, etc.
- Most districts quote high construction cost as the most significant factor influencing the wide use of approach slabs.
- Approach slab use can be adopted as an effective measure for differential settlement problems, but it is not a panacea and other methods also can be used to mitigate this problem, such as embankment fill, compaction, drainage, etc.
- No maintenance record from Kentucky or other states has proven life-cycle maintenance cost for approach slabs are lower than flexible approaches.

5.4 Abutments

Many abutment designs exist and different abutment types have been tried on bridges throughout the United States, however, a consensus has not been reached on the best type of abutment to minimize and/or eliminate the bump problem caused by approach

settlement. Generally there are two types of abutments that are usually adopted widely by various DOTs: one-integral (conventional) and integral type. The non-integral or conventional type of bridge abutments (Figure 5.2) have bearing connections and expansion joints to provide the superstructures with a certain amount of lateral movement between the abutment and the bridge deck (Wahls, 1990). The integral bridge abutment type (Figure 5.3) was developed in order to eliminate the use of bearing plates and to reduce potential maintenance problems (Horvath, 2000). The integral abutment is a stub abutment connected to the bridge superstructure tightly without any expansion joints (Wahls, 1990). Both non-integral abutments and integral abutments are commonly employed by many state transportation agencies including Kentucky.

In chapter three, the abutment type is divided into three categories: closed, spill-through, and perched. Generally, closed and spill-through abutments fall into the category of nonintegral abutments, while perched abutments can be classified as non-integral or integral abutments. In the chapter of data analysis, there is no significant association between abutment type and approach settlement levels. However, several studies have shown that the type of bridge abutments plays an important role in the form of approach settlement. Pierce et al. (2001) concluded that the bridge approaches with integral abutments tend to provide a smoother surface than the bridges with non-integral abutments. Another study (Wahls, 1990) reported a problem related to cracking and bulking at the approach pavement due to a lateral cyclic movement of the abutment from thermal movement induced stresses at the bridge decks. The biggest problem for integral abutments is the lateral movements. The bridge superstructure will be expanded and contracted by seasonal air temperature fluctuations because of concrete thermal strain properties.



Figure 5.2 Simplified cross section of non-integral abutment bridge (Greimann et al., 1987; White et al., 2005)



Figure 5.3 Simplified cross section of integral abutment bridge (Greimann et al., 1987; White et al., 2005)

According to the interview with bridge engineers from various districts, abutments supported on pile bent (perched) are generally more economical than spill-through (open column) abutments on spread footings. They usually adopt the pile bent abutments first when there is a choice between the two types of abutment. When non-integral abutments are necessary, piles that resist horizontal thrust by battering the front row of piles 1 to 3 are needed. For new bridges, the structural design manual of KYTC suggests that an integral abutment is preferable than non-integral abutments, and backwalls and expansion joints are recommended to be constructed for pile bent abutments. In addition, different abutments have different requirements for embankment backfill in design and construction in Kentucky.

5.5 Drainage

Approach drainage is another key factor that influence the occurrence of bump caused by approach settlement at the end of bridges. Water collected on the road surface and bridge pavement can flow into the underlying fill materials due to ineffective seals at the joins or cracks between the bridge approach and the abutments, and this infiltrated water can do significantly damage to the bridge approach. For bridge without approach slabs, the seeped water will immediately induce settlement, causing a bump. For bridges even with approach slabs, erosion can amplify the development of voids caused by compression of backfill and lateral deformations (Dupont and Allen, 2002). In this sense, the design of bridge approaches has to be incorporated with an efficient drainage system (Abu-Hejleh et al., 2006). Dupont and Allen (2002) also pointed out that the construction costs added to incorporate a good drainage system are not high when compared to the expensive maintenance costs that they might experience during the service life of the bridge.

Therefore, the significance of designing bridge approaches with effective seals and good drainage conditions cannot be overemphasized.

In the last chapter, drainage design cannot be treated as a quantitative or qualitative variable included in the predictive models due to a fact that it is difficult to evaluate the performance of drainage plan for a bridge based on very limited record on this information in Kentucky. Also it is too simple to consider drainage as a binary variable (considered drainage design or not) because most bridges have considered drainage design. Thus this section mainly summarizes the current practices used by KYTC and other transportation agencies.

Generally, bridge approach must include both surface and subsurface drainage designs. For surface drainage design, Briaud et al. (1997) introduced a way of designing wingwalls curb-to-curb that could direct the water away from the bridge joints (Figure 5.4). For subsurface drainage design, a method that has been considered by most DOTs is the use of porous backfill material or limiting the percentage of fine particles in the fill material to reduce material plasticity and enhance drainage properties. Different layers of granular materials should be arranged with requirements in sequence and thickness in order to prevent water exiting the wall face and causing erosion. Furthermore, outlets should be installed to discharge of seepage away from the reinforced soil structure. Abu-Hejleh et al. suggested a drainage system by using mechanically stabilized earth (MSE) walls (Figure 5.5). Another subsurface drainage design introduced by Nassif (2002) is to construct a layer of filter material before placement of the backfill and then install perforated pipes at the bottom to discharge the collected water (Figure 5.6).



Figure 5.4 Approach slab joint details at pavement edge (Briaud et al., 1997)



Figure 5.5 Mechanically stabilized earth (MSE) walls system under sleeper slab (Abu-Hejleh et al., 2006)



Figure 5.6 Drainage layer of granular material and collector pipe (Nassif, 2002) Based on the recommendations reported in the literature, the techniques or measures to improve drainage conditions include:

- use of porous backfill material,
- make side slopes flatter,
- use of a curb-to-curb design for erosion control and effective drainage of water away from the bridge structure and approach slab system (Figure 5.4),
- place drains at the back and/or low points of the embankment backfill in order to discharge groundwater,
- use of a large diameter surface drain and gutter system in the shoulder of the approach slab for bridges with approach slabs,
- use of a geo-composite vertical drainage system around the embankments,
- plastic drainpipes, weep holes in the abutments;

- use of a thick layer of tire chips as an elastic zone behind the abutment with a high capacity of drainage,
- use of interceptor drains on the back slope,
- perform periodic maintenance;
- mechanically stabilized earth (MSE) structures (Figure 5.5),
- construct a layer of filter material before placement of the backfill and then install

According to a review conducted by White et al. (2005), there main variations of drainage system were adopted across the nationwide: (1) porous backfill around a perforated drain pipe; (2) geotextiles wrapped around the porous fill; and (3) vertical geocomposite drainage system (Figures 5.7 to 5.10). From this study, approximately 14 out of 16 states have used a combination of two or more of the above three methods to increase the drainage efficiency (Table 5.6).



Figure 5.7 Schematic of porous fill surrounding subdrain (Iowa DOT, 2005)



Figure 5.8 Schematic of granular backfill wrapped with geotextile filter material (Wisconsin DOT, 2003)



Figure 5.9 Schematic of geocomposite vertical drain wrapped with filter fabric (Missouri DOT, 2005)

State	Porous Fill	Geotextile	Geocomposite Drainage System
Iowa	Х	-	-
California	Х	Х	Х
Colorado	-	Х	Х
Indiana	Х	Х	-
Louisiana	Х	Х	Х
Missouri	-	Х	Х
Nebraska	-	Х	Х
New Jersey	Х	Х	Х
New York	-	-	Х
North Carolina	Х	Х	-
Oklahoma	Х	Х	-
Oregon	Х	Х	-
Tennessee	Х	Х	-
Texas	Х	Х	-
Washington	Х	-	-
Wisconsin	Х	Х	-

Table 5.6 Drainage method used by various states (White et al., 2005)

By talking with the local bridge engineers in various districts, most engineers cited that the use of porous backfill behind the abutment would enhance the drainage capacity and would reduce the erosion around the abutment. In Kentucky, specifications from AASHTO govern the requirements of material type and use. Several districts sometimes adopt granular backfill wrapped with geotextile as drainage systems. Currently, no special provisions related to the design of bridge approach drainage are provided by KYTC.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

A bridge approach is usually built to provide a smooth and safe transition for vehicles from the roadway pavement to the bridge structure. However, differential settlement between the roadway pavement resting on embankment fill and the bridge abutment built on more rigid foundation often creates a bump in the roadway. In the United States, the highway agencies have been spending considerable amounts of their maintenance budgets to minimize or eliminate the bump problems caused by approach settlement at bridge ends. Moreover the maintenance work usually results in traffic delays and unsafe ride for motorists in heavy traffic areas. Prediction of bridge approach settlement can play an important role in selecting proper design, construction, and maintenance techniques and/or measures. On the one hand, bridge designers could use a predictive model to predict the approach settlement level based on foundation, approach, embankment, and other bridge characteristics for a new bridge. And then apply corresponding techniques and/or measures in the preliminary phase to prevent or minimize the settlement problems that may occur in the future. On the other hand, the bridge maintenance engineers could use a predictive model to evaluate the performance of an approach for an existing bridge based on the current situations in use such as approach year, geographic regions, Average Daily Traffic (ADT), and approach type. And then implement effective maintenance activities for correcting distressed approaches.

A study based on statistical methods was carried out to identify the predominant factors that may significantly influence the formation of the approach settlement and to figure

out how to develop a model for predicting approach settlement level by quantifying these count or categorical data as model inputs. Two samples were obtained by different selection methods: sample one with 87 bridges was formed by a survey of local bridge engineers from each transportation district, and sample two was randomly generated with 600 bridges from an internal network server "Pontis" which was used for storing the inspection history of approaches of most of the bridges in Kentucky. Previous studies usually adopted a micro method to evaluate the approach performance based on observed approach settlement. A macro method based on a combination of maintenance times, maintenance measures, and observed settlement was used to classify the differential settlement scale as minimal, moderate, and severe, corresponding to the approach performance status good, fair, and poor. Ten independent variables that may have an important contribution to the formation of approach settlement were identified. The independent variables of interest both consist of count data and categorical (ordinal and nominal) variables. The outcome (response) variable is ternary: minimal, moderate, or severe, and it is assumed as ordinal under the assumption that the levels of approach settlement have a natural ordering (low to high), but the distances between adjacent levels are not consistent. If the ordinal logistic analyses violates this assumption, a less restrictive method of multinomial logistic method would be adopted. Chi-square test was employed first to identify whether there is an association between each predictor and approach settlement levels. Then both methods of ordinal logistic regression and multinomial logistic regression were used to develop the comprehensive models to predict approach settlement levels considering all predictors. Two predictive models were developed to estimate the probability of occurrence of each of the three settlement levels
as well as to estimate the odds of severity choice as a function of the covariates and to express the results in terms of odds ratios for severity choice given bridge characteristics. The users can select one or two models to predict the approach settlement level for a new bridge or an existing bridge based on different purposes.

Five transportation districts were visited to obtain the current practices that have been using for alleviating the bump problems caused by approach settlement. A base of techniques and measures regarding bridge approaches in design, construction, and maintenance was developed for providing bridge engineers the prescriptive correction measures that could be applied to predicted differential settlement. Techniques and measures in the terms of foundation soil, embankment backfill material, approach slab, abutments, and drainage were collected and summarized.

6.2 Conclusions

The primary objective was met through the statistical analyses performed that predict the approach settlement levels for a new or an existing bridge given bridge characteristics in terms of approach, embankment, abutment, traffic volume, and foundation. From the previous results, there are several key conclusions that can be made:

 It is imperative that the approach system be treated as a stand-alone design objective in Kentucky. From the literature review, several states, such as Iowa, Texas, Wisconsin, have initiated a design manual regarding approach design.
 From the district interviews in Kentucky, most of issues related to approach design are directed by project manager. Maintenance techniques or measures are in a great variation among districts when excessive approach settlement occurs.

- It is appropriate to use the macro method based on a combination of maintenance times, maintenance measures, and observed settlement to classify the differential settlement level. Observed settlements are not necessarily needed to evaluate the performance of approaches if a record regarding approach maintenance activates exists.
- A legible, accurate, and accessible record keeping system regarding inspection/maintenance of bridge approaches is an effective and straightforward way of discovering and managing bridge approaches when excessive approach settlements occurs.
- 4. Sample one: The results from logistic regression show that approach age, transportation districts, and foundation soil depth are the three most important factors influencing the formation of approach settlement. The probability of being in a higher settlement level will decrease as the approach age increases. District one, district ten, and district eleven behave better than other districts in the treatment of differential settlement at bridge ends. In addition, the probability of being in a higher settlement level will decrease as foundation soil depth for a bridge increases.
- 5. Sample two: Transportation district, approach age, average daily traffic, and approach type are the four most important factors that contribute to the development of approach settlement. District one, district three, and district ten behave better by comparing to other districts in the treatment of differential settlement at bridge ends. There is a positive correlation between AGE and SEVERITY, which implies that the probability of being in a higher level of

approach settlement will increase as the bridge age increases while holding all other predictors constant. As average daily traffic for an approach increases, the probability of being in a higher settlement level will increase. Furthermore, flexible approaches tend to have a higher probability of being in a higher settlement level than rigid approaches.

- 6. There is a significant association between approach type and approach settlement levels. Concerning fewer approach slabs are used in Kentucky, the use of approach slabs was demonstrated to be useful on mitigating bump problem based on the performance of approach slabs that have been constructed in Kentucky. The use of approach slabs could enhance the performance of approaches as transitions between roadway and the bridge. However, the effectiveness is not significant because the effective ratio is slightly larger than 1.
- 7. The variation trends of the predicted probability of minimal versus the statistically significant predictors met well with the logistic regression results for sample one. The probability of being in the settlement level of minimal will increase as approach age increases. District one, ten, and eleven show a higher probability of being in the settlement level of minimal than other districts. The probability of being in the settlement level of minimal will increase at first as the foundation soil depth increase by 25 feet and then decrease as the foundation soil depth continues to increase.
- 8. The variation trends of the predicted probability of minimal versus the statistically significant predictors met well with the logistic regression results for sample two. District one, three, and ten show a higher probability of being in the settlement

level of minimal than other districts. The probability of being in the settlement level of minimal will decrease as approach age increases. The probability of being in the settlement level of minimal will decrease as the average daily traffic increases. Rigid approaches tend to have a higher probability of experiencing settlement levels of minimal than flexible approaches.

- 9. The most common ways that have been using by Kentucky to improve highly compressible foundation soils are preloading the foundation soils and excavation and replacement. Two easy and reliable alternatives are proposed when situations do arise that the foundation soils are not adequate. One is to reduce the loads applied to the foundation, and the other method is to improve the properties of the foundation soil by grouting chemical. KYTC has not given a manual that will guide designers and constructors how to carry out different ground improvement methods for a particular field situation.
- 10. Many districts reported that they are not willing to accommodate the preloading and/or precompression periods since this process may lead to construction delay and drive initial construction costs higher.
- 11. Precompression technique in embankment construction is reported as a successful practice by most bridge engineers. Another effective way of solving the excessive approach settlement is the use of flowable fills.
- 12. The use of Approach slab varies dramatically among districts. No specific manuals for approach slab have been established in Kentucky to specify some design and/or construction issues. Most districts quote high construction cost as the most significant factor influencing the wide use of approach slabs. No

maintenance record from Kentucky or other states has proven life-cycle maintenance cost for approach slabs are lower than flexible approaches.

- 13. Abutments supported on pile bent (perched) are generally more economical than spill-through (open column) abutments on spread footings. KYTC suggests that an integral abutment is preferable than non-integral abutments.
- 14. The use of porous backfill behind the abutment would enhance the drainage capacity and would reduce the erosion around the abutment. Several districts sometimes adopt granular backfill wrapped with geotextile as drainage systems. Currently, no special provisions related to the design of bridge approach drainage are provided by KYTC.

6.3 Recommendations for Future Research

This research is limited in the construction engineering body of knowledge, which provides a great opportunity for growth in some areas such as structural engineering, transportation engineering, and statistics, both in depth and breadth. In view of the present study, there are several recommendations for additional research.

- 1. A sample with more bridges obtained by surveying bridge engineers should be used for logistic regression. In logistic regression, if the sample size is small, it may lead to an unstable model.
- 2. Other lurking variables, such as temperature cycle, connection between the approach and the bridge, compressibility characteristics of embankment, and drainage design of approaches, may be included in the present models.
- 3. The effect of drainage on the formation of approach settlement should be studied in depth based on bridge characteristics in Kentucky. A consensus has been

reached nationwide that drainage plays a very significant role in the development of differential settlements at bridge ends.

- 4. The developed models in this research are based on judgment of local bridge engineers or inspection record from KYTC. Field visits should be conducted to verify the results from the predictive models. The true approach settlement should be measured to compare with the results from the models. If there is a database for the record of the observed settlement for most of the bridges in Kentucky, other statistical methods can be used to predict the approach settlement in inches.
- Predictive models are only built on the bridges from Kentucky, bridges from other states can be included to develop a more comprehensive use nationwide by this method.
- 6. Explore the potential of using the characteristics on construction of abutment and backfill as inputs to develop a model. Interviews with the construction engineers are recommended as well as frequent visits to observe the abutment and backfill construction.
- 7. Some information on foundation soil used for developing the models are not very accurate. Field tests need to be carried out to investigate the foundation soils when this information cannot be obtained from bridge design plans.

APPENDICES

Appendix A: Summary of Major Studies on Bridge Approach Settlement

No.	Author, Institution & Time	Title	Main Works & Key Findings
1	Elizabeth; TxDOT; 2012	The Bump at the End of the Railway Bridge	 Investigate the complete track response resulting from a bump/dip Quantify an acceptable slope for track geometry under freight traffic Examine the influence of various design components on track response for the bump/dip Develop a prototype track transition solution and assist in analyzing the performance of a full-scale field test. A 4-D dynamic numerical model was developed to simulate a train passing over a bridge approach system using the program LS-DYNA The resulting impact forces, track deflection, ballast and subgrade pressures that were generated by the bump/dip were then evaluated. Based on the survey and simulation results, an acceptable slope can be defined.

	1		
			• Literature review of causes of
			bridge approach settlement, current
			mitigation methods and
			maintenance technique. Field test
			for some selected bridges.
			Introduction of backfill
			specification, field instrumentation
			plan
			• The movements of the approach
			fills that have granular foundation
			soils (Hemlock and Cranberry) and
	Ghorbanpoor, Al; Koutnik, Therese Ellen; Helwany, Sam; Wisconsin DOT; 2007	Evaluation of bridge approach settlement mitigation methods	less than 5 to 7 feet of fill were
			insignificant over five years
			compared with the movements of
2			the approach fills (Western and
			Beloit) with cohesive foundation
			soils over two years
			• Embankment side slopes that settle
			and slough (Western and Beloit)
			resulted in erosion and/or
			movement of backfill material
			• The cost of flowable fill is greater
			than geosynthetic reinforced fill
			for small quantity jobs
			• Laboratory and field tests need to
			be carried out to investigate the
			effectiveness of using hydraulic
			fills as a method for alleviating
			bridge approach settlements

			• Void development from backfill
			collapse following saturation,
			severe backfill erosion, poor
			surface and subsurface water
			management, and poor
			construction practices mainly
			contribute to settlement problems
			of the approach pavements of
			bridges
			• Erosion can lead to problems
			including: exposure of the H-piles,
			failure of the slope protection
	White et al; Iowa DOT; 2007	"Underlying"	cover, severe faulting in the
		Causes for Settlement of Bridge Approach Pavement Systems	approach pavement, and loss of
			backfill around subdrain elements
3			• Problems in void development,
			water management, and pavement
			roughness were generally more
			pronounced with integral abutment
			bridges than non-integral
			• Backfill materials should be placed
			outside the range of bulking
			moisture contents and should be
			less susceptible to erosion
			• The surface water management
			system should be designed to shed
			water to the base of the
			embankment and the subsurface
			drainage system to provide an easy
			pathway for infiltrating water to
			escape

		Field	
4	Hoppe; Virginia DOT; 2006	Measurements on	
		Skewed Semi-	• Data obtained by monitoring earth
		Integral Bridge	pressure cells, load cells, and strain
		with Elastic	gages would be useful for future
		Inclusion:	endeavors
		Instrumentation	
		Report	
			• Flowfill is recommended in certain
			difficult field conditions (e.g., to
			fill and close up voids, in areas
			where compaction is difficult,
			easier to place around an
			embankment slope)
			• The use of the MSE or GRS
			abutment system is the best system
		Flowfill and MSE	to alleviate the approach bridge
		bridge	bump problem
	Abu-Hejleh et	approaches:	• The high quality backfill materials
5	al; Colorado	Performance, Cost	should be placed under the sleeper
	DOT; 2006	and	slab
		Recommendations	• The length of the approach slab
		for Improvements	should be related to the depth of
			the abutment wall and the
			magnitude of the projected post-
			construction settlements
			• The drainage system is very
			important to collect and drain any
			surface water before it reaches and
			softens the soil layers located
			beneath or around the sleeper slab

6	Lenke; New	Settlement Issues	• MSE walls have fewer problems
	Mexico DOT;	– Bridge	with approach slab settlement
	2006	Approach Slabs	issues than other types of bridge
7	Hoppe; Virginia Transportation Center (TRC)/Virginia DOT; 2005	Field Study of Integral Backwall with Elastic Inclusion	 An elastic inclusion consisting of a layer of elasticized Expanded Polystylene (EPS) 0.25 m significantly reduced earth pressures and approach settlements at the semi-integral bridge The well-compacted select backfill material at bridge approaches is necessary Short approach slabs could be sufficient to provide a grade transition Shorter approach slabs would be easier for the superstructure to push and pull during cyclic movements, and would exert less stress on the backwall if they settle Thermally induced lateral movements of the superstructure may not be equal at both abutments

	Jayawickrama		• Saturated base/subgrade material at
			the end of bridge could be a major
			problem
			• Use of geotextiles fabric beneath
		Water intrusion in	the joints to avoid loss of material
8	et al.; TxDOT;	base/subgrade	by erosion
	2005	material at bridge	• Approach slab stabilization to
		ends	control void development and
			cross/slot stitching of approach
			slabs and concrete pavements for
			controlling further development of
			cracks
			• After settlement is increased to a
	Cai et al.; Louisiana TRC/ LADOT;	Determination of	larger value, it no longer affects
			the performance of slab since
			approach slab completely loses its
		between the	contact with soil and becomes a
9		bridge concrete	simple beam
		bridge concrete	
		approach slab and	• The developed procedure can be
	2005	approach slab and	• The developed procedure can be used in designing the approach
	2005	approach slab and embankment	• The developed procedure can be used in designing the approach slab to meet the established
	2005	approach slab and embankment settlement	• The developed procedure can be used in designing the approach slab to meet the established deformation requirements
	2005	approach slab and embankment settlement	 The developed procedure can be used in designing the approach slab to meet the established deformation requirements Due to over stress of bolts and

			• Void development under the
			bridge approach is observed within
			one year of bridge construction,
			indicating insufficient moisture
			control/compaction and poor
			backfill material
			• Water management around the
			bridge is a major problem at most
		Identification of	of the inspected bridges. Several
	David White,	the Best Practices	abutment subdrains were observed
10	Sri Sritharan;	for Design,	to be either blocked with soil, dry,
10	Iowa DOT;	Construction, and Repair of Bridge Approaches	indicating no water flow, or
	2005		collapsed
			• Grouting under the approach slab
			does not necessarily prevent
			further settlement or loss of
			backfill material due to erosion
			• Use a more effective joint sealing
			system at the joint between road
			and bridge approach
			• Reduce time-dependent post
			construction settlements
		Simple Design	• Three alternatives are
		Alternatives to	recommended to improve drainage
	Mekkawy et	Improve Drainage	and alleviate erosion: 1) use
11	al.; Iowa DOT;	and Reduce	geocomposite drain with granular
	2005	Erosion at Bridge Abutments	backfill reinforcement, 2) use tire
			chips behind the bridge abutment,
			and 3) use porous backfill material

			Use of Controlled Low-Strength
			Material (CLSM) behind bridge
			abutments to avoid the problem of
			settlement
			• Compressible soils beneath the fill
			may settle beneath the weight of
			the embankment, causing
		Use of Controlled	settlement of the embankment
	M. Schmitz; Kansas DOT;	Low-Strength Material as	itself. This may lead to significant
12			differential settlement between the
	2004	Abutment	approaches and bridges, which are
		Backfill	usually built on drilled sha fts or
			piles that extend to bedrock
			• Stone columns would not only
			accelerate consolidation but also
			transfer loads to less compressible
			units. CLSM would complement
			stone columns well, acting as a
			solid fill with little settlement.

			Geotechnical (soil mechanics)
			techniques can be used to predict
			when the potential for a problem
			exists. The various means of
			reducing the settlement of the
			embankments need to be
			established on a case -by-case
			basis as determined by the design
			interactions between the
			geotechnical engineers and the
	Ronaldo Luna; MoDOT; 2004	Evaluation of	bridge designers
		Bridge Approach Slabs Performance and Design	• Modern numerical method is used
13			to determine the embankment
			settlement and it compared well
			with the general observed
			conditions. The use of typical
			geotechnical data for input
			parameters results in useful but
			relatively large ranges of the
			predicted settlement due to the
			inability of assessing modulus and
			related deformation parameters
			• The construction sequence has a
			significant effect on the final
			performance of the embankment
			and bridge approach slab

		• The compressibility of the soil is	
			contributing to the development of
			the bump
			• The transition zone of the approach
			embankment is about 12 m with 80
			percent of the maximum settlement
		The bump at the	occurring in the first 6 m for a
14	Seo et al.;	end of the bridge:	uniform load case
	TxDOT; 2003	an Investigation	• The size of the sleeper slab and
			support slab influences the
			settlement of the slab. The
			optimum width of both slabs is 1.5
			m
			• A single-slab at least 6 m long and
			0.3 m thick is recommended for an
			approach slab
			• Steel H-piles oriented in the weak-
			axis bending area is a good choice
			for support integral abutment
	Arsoy et al.;	Performance of	bridges
15	VTRC/VDOT;	Piles Supporting	• Pipe Piles will cause higher stress
	2002	Integral Bridges	in the abutments than steel H-piles
	2002		• Concrete piles are not a suitable
			choice. Tension cracks due to
			cyclic lateral load can reduce their
			vertical load capacity

• The number one r	eason for the
bump is the settle	ement of the
Finite element embankment fill for	ollowed by the
modeling of loss of fill by	v erosion
bridge approach, • The settlement a	t the bridge
16 Nassif; transition slabs approach is wors	se when the
NJDOT; 2002 using ABAQUS, embankment is high	h and the fill is
and identifying clay	
the probable cause • The settlement a	t the bridge
of cracking approach is lesses	ned when an
approach slab is	used and the
abutment fill is cen	nent stabilized
Lowered approace	ch slabs with
asphalt over	erlays
Require settlement	periods and/or
surcharges prie	or to final
construc	tion
Dupont and • Design Mainten	nance plans
Allen; Movements and concurrent to cons	truction plans
17Kentuckysettlements ofImplement specifica	ations for select
Transportationhighway bridgefill adjacent to	abutments
Center (KTC); approaches • Improve drainage c	lesigns on and
2002 around appr	oached
Require bridge	approach
warrant	ies
Reduce the sid	e slope of
embankm	nents
Improve approach	h slab design

			• A bump that is allowed to persist
			increases the chance of damage to
			the bridge deck from the dynamic
			impact of vehicles
			• Damage to the bridge deck can
		Fabric Reinforced	also be caused by snowplows in
18	Marquart, M.;	Backfill under	the winter
10	NDDOT; 2002	Approach Slabs	• Integral bridge abutments appear
			to be a special case where a bump
			is consistently created resulting
			from temperature cycles and the
			associated compression and
			decompression of the approach fill
			by the abutment wall
	Investigation of settlement at		• The number one reason for the
			bump is the settlement of the
		embankment fill followed by the	
		Investigation of settlement at	loss of fill by erosion
			• The soil near the abutment was
			weaker and wetter than the soil
			away from the abutment
19	Ha and Briaud;	bridge approach	• The soil near the abutment had a
-	TxDOT; 2002	slab expansion	relatively high Plasticity Index (PI)
		joint: survey and	for an embankment fill
		site investigations	• A bump rating number, BR, and a
			bump index number, BI, are
			proposed to document the severity
			of existing bumps and to evaluate
			the likelihood of developing a
			bump at a site, respectively

			• Conducted visual inspection and
			quantitative assessment of bridge
		Investigation into	approach slabs located at 25
	Pierce, Charles	improvement of	bridges in 11 counties across South
20	E; SCDOT;	bridge approaches	Carolina, and assessed the
	2001	in South Carolina	performance level of bridge
			approach slabs and determine the
			rideability of the road-to-bridge
			transition
	Parsons; Kansas DOT; 2001		• Eight embankments constructed
			between 1994 and 2000 were
			selected for undisturbed field
21			sampling. Two borings were
			drilled in each embankment and
		Compaction and	shelby tube samples were collected
		settlement of	for testing at regular intervals.
21		existing	Samples of the cuttings were also
		embankments	collected for testing. A telephone
			survey of all state DOTs was
			conducted to assess current
			practice with regard to
			specifications for compaction of
			fills.

			• GRS abutment and piers are
		Results and	practical alternatives used in
		Recommendations	bridge support
	Abu-Heileh et	of Forensic	• GRS should not be used in a scour
22	al.: Colorado	Investigation of	situation
	DOT; 2001	Three Full-Scale	• GRS piers are suitable for remote
	,	GRS Abutment	locations, since it can be
		and Piers in	constructed or repaired by using
		Denver, Colorado	small construction equipment
			within a few days
			• Full-width approach slabs are used.
	Hoppe; VTRC/VDOT; 1999		It reduces erosion of the approach
			fill
			• Placing approach slabs below the
			road surface facilitates resurfacing
		Guidelines for the	operations
		use, design, and	• Drainage system between the top
23		construction of	of the approach slab and the
		bridge approach	surface of the road should be
		slabs	provided
			• Pre-cambering may be employed
			to compensate differential
			settlement at bridge approaches
			resulting from differing
			foundations beneath the bridge and
			theroadway

			• Identified the factors that			
			contribute to total approach			
		Assessment of	settlement in pile supported			
	Sankar;	mitigating	approach slabs in southeastern			
24	Louisiana	embankment	Louisiana. The main factor			
	TRC; 1999	settlement with	affecting slab settlement is			
		pile-supported	downdrag, or negative skin			
		approach slabs	friction, load imposed on the pile			
			due to the weight of the roadway			
			embankment.			
		Use of fabric				
	Reid et al.; SDDOT; 1999	reinforced soil				
		wall for integral abutment bridge	• Voids reduced by using the rubber			
25			tire chips behind the integral			
23		end treatment and	abutment			
		investigate the	• Cyclic movements do not affect			
		effectiveness of	the voids			
		present design				
			• The use of Control Low-Strength			
		Construction of	Material (CLSM) as an approach			
	Snethen et al.;	CLSM approach	ambankmant fill material as a			
26	Ohio DOT;	embankment to	simple and cost offective method			
	1998	minimize the	simple and cost effective method			
		bump at the end	to reduce the potential for			
		of the bridge	developing the bump at the end of			
			the bridge			

27	Hearn; Faulted Colorado pavements at DOT; 1997 bridge abutments		 Synthesis on faulted pavements at bridge abutments; Occurrence of pavements faults. Reported causes; Mitigation of pavement faults; Observed total settlements;
		Differential settlement in bridges; Limits on tolerable settlements for bridges.	
28	Briaud and Jame; TxDOT; 1997	Settlement of bridge approaches : (the bump at the end of the bridge)	 Identified and described techniques that have been used to alleviate the problem of the bump at the end of the bridge including the location and cause of settlement and methods used to reduce settlement Types of interaction between various divisions of the DOTs in the design, construction, and maintenance of bridge approaches are addressed

			• Thermal induced movements of
			integral abutments are responsible
			for void development
		Survey done to	No problem with the material used
		isolate and	• No problem with the material used
		determine the	as a backfill
	Schaefer and	mechanisms	• Voids are not developed due to
29	Koch;	controlling	erosion
	SDDOT; 1992	backfill to reduce	• Cracking is due to loss of support
		void development	• Mud jacking does not affect the
		under bridge	formation of voids
		approaches	• Non-integral abutment reduces the
			problem of voids
			• Maintenance cost increases by
			using integral abutments
			• Settlement problem is due to the
			absence of drainage
			• Major portion of the settlement
			occurs within first twenty years
		Evaluation of	• Skewed approaches have higher
		causes of	approach settlement than non-
	Laguros and	excessive	skewed approaches
30	Zaman;	settlements of	• Regression techniques were used
	OKDOT;1990	pavements behind	to develop an empirical
		bridge abutments	relationship between the approach
		and their remedies	settlement and the causative
			parameters such as age of the
			approach, embankment height,
			traffic volume, and skewness of
			the approach.

31	Wahls; NCDOT; 1990	Design and construction of bridge approaches and to revise and update the report of KYDOT (1969)	 Bridge approach settlements are caused due to time dependent consolidation of embankment, poor compaction, drainage, and erosion of abutment backfill Lateral creep of foundation soils and movements of the abutment Type of abutment and foundation also affect the performance Differential settlement can be minimized by using shallow foundations
32	Greimann et al.; Iowa DOT; 1987	Pile design and tests for integral abutment bridges due to the effect of temperature changes	 Horizontal displacement had no effect on the vertical load capacity Use of a pre-drilled hole is recommended as a pile construction detail to reduce the pile stresses significantly when horizontal displacements of the pile occur
33	Stewart; Caltrans; 1985	Survey of Highway structure approaches	 Structure approach slab policy Design policies and procedures Structure approach slab design concepts Construction sequence and details for rehabilitation projects

		Long term				
		movements of	• Settlement of bridge approach			
		highway bridge	foundations contributes			
34		approach	significantly to settlements of			
	Hopkins,	embankments and	approach pavements			
	KyDOT; 1985	pavements by	• Improper compaction, lateral			
		surveying and	movements, erosion of materials,			
		observation of six	and secondary compressions are			
		bridge sites from	the causes for long-term movement			
		1966 to 1985	of bridge approaches			
			• The ultimate load capacity for			
	Greimann et al.; Iowa DOT; 1984	Deign of Piles for Integral Abutment	frictional piles was not affected by			
			lateral displacements of up to 4 in.			
			for Hpiles and up to 2 in. for			
35			timber and concrete piles			
		Bridge	• The ultimate load capacity was			
			considerably decreased if lateral			
			displacements greater than 2 in. for			
			end-bearing H- piles			
		Performance of	• Spread footing on compacted fill			
		Highway Bridge	supporting the bridge abutment is			
36	DiMillion;	Abutments	very reliable and inexpensive			
50	WSDOT; 1982	Supported by	• The superstructure with a spread			
		Spread Footing on	footing can withstand temperate			
		Compacted Fill	settlement (1-3 in.) without distress			
			· · · · ·			

			Concrete bridge approaches are			
			better than bituminous bridge			
			approaches			
			• Progressive failure or creep of the			
			approach is a cause for the			
		Preliminary	development of an approach fault			
			• Erosion of soil from abutments			
		survey done on	contributes to development of			
		the existing	defective bridges.			
		bridges to	• Traffic is not a cause for the			
		calculate	settlement			
		settlement of highway bridge approaches and embankment foundations by using special experimental design and construction	• Backfilling around abutments wi			
			a granular material did not arres			
	Hopkins:		the development of faulted			
37	Порило, Курот: 1969		approaches			
			• Settlement of the approach			
			foundation and embankment			
			contributes significantly to			
			settlement of bridge approaches			
			and approach pavements			
		features at	• Replacing the soft compressible			
		selected bridge	material with rock or compacted			
		sites	material			
			• Pre-consolidate using surcharge fill			
			• Allow sufficient time for			
			consolidation of the foundation			
			under the load of the embankment			
			• Use of vertical sand drains and			
			drainage system			

	Longitudinal camber is provided at
	the approaches

Appendix B: Survey of Requesting Bridges with Different Settlement Levels for Comprising Sample One

Survey Designation:

One of the most important tasks of this project is to select bridges and conduct site visits to evaluate "bump" issues at bridge ends based on maintenance information. This survey will serve to help identify and quantify differential settlement at bridge ends throughout the state. The purpose of this survey is to:

- Obtain information regarding the existence of bridges with "bump" issues;
- Identify major causes of differential settlement at bridge ends;
- Evaluate the existing record keeping procedures regarding maintenance of "bump" issues.

1. THANK YOU FOR YOUR ASSISTANCE!

Name of Respondent:

Job Title:

E-mail Address:

2. Please list five bridges that you believe have the worst "bump" conditions in your district. (Fill in the information as thoroughly as convenient) Please use the following scale to rank the condition: 1= Major bump, 2= Moderate bump, 3= Minor or no bump.

Bridges	Bridge ID/Number/Mile post	Route	County	Condition	Remarks
Bridge 1					
U					
Bridge 2					
0					

Bridge 3			
Bridge 4			
Bridge 5			

3. In what cases does the "bump" problem appear to be minimized? Please list five bridges that you consider to be in good condition in your district. (Fill in the information as thoroughly as convenient) Please use the following scale to rank the condition: 1= Major bump, 2= Moderate bump, 3= Minor or no bump.

Bridges	Bridge ID/Number/Mile post	Route	County	Condition	Remarks
Bridge 1					
Bridge 2					
Bridge 3					
Bridge 4					
Bridge 5					

4. In what cases does the "bump" problem appear to be moderate? Please list five bridges that you consider to be in moderate condition in your district? Please list five bridges that you consider to be in good condition in your district. (Fill in the information as thoroughly as convenient) Please use the following scale to rank the condition: 1= Major bump, 2= Moderate bump, 3= Minor or no bump.

Bridges	Bridge ID/Number/Mile post	Route	County	Condition	Remarks
Bridge 1					

Bridge 2			
Bridge 3			
Bridge 4			
Bridge 5			

If you have any questions, please call Professor Timothy R. B. Taylor on (859) 323-3680 or contact him on E-mail at <u>tim.taylor@uky.edu</u>. We would appreciate your response by April 1st, 2014

Bridge_	Dist	Len	Wi	Арр	AD	AbuT	АррТ	EmbH	FSoilD	Consist	Seve
ID	rict	gth	dth	Age	Т	уре	уре	eight	epth	ency	rity
061B00 099N	11	136	24	4	246 0	3	1	7	21	2	3
056B00 495N	5	281	66	5	582 00	3	1	32	15	2	2
		256			800						
489N	5	.2	30	5	00	2	1	29	8	2	2
056B00	-	159	24	-	582	4	4	47	0		2
492N	5	.7	24	5	00	1	1	17	0	4	2
056B00	Е	200	20	E	582	2	1	24	17	2	2
494N	5	308	30	5	00	3	T	24	17	3	Z
049B00	C	000	24	C	122	2	2	22	10	2	2
072N	б	889	24	б	00	3	Z	22	12	5	J
118B00	11	175	40	c	401	2	2	10	10	2	2
123N	11	.9	40	б	0	3	Z	18	19	Z	3
115B00	Λ	602	40	0	706	2	2	10	12	2	2
065N	4	005	40	0	700	5	2	10	12	5	З
056B00	Б	252	60	0	174	n	1	10	0	4	n
488N	J	555	00	0	00	Z	T	10	0	4	2
041B00	6	255	18	8	296	R	1	5	1/	2	2
062N	0	.6	10	0	250	5	T	5	14	2	2
041B00	6	242	28	Q	202	2	1	19	Q	2	2
065N	0	.5	20	0	393	J	T	10	0	2	5
039B00	6	286	24	Q	294	2	1	21	1/	2	2
048N	0	.5	24	0	00	5	T	21	14	2	5
041B00	6	450	30	8	244	3	1	33	7	2	3
069N					0						

Appendix C: Detailed Data Information of Sample One

041B00 067N	6	236	24	8	484	3	1	4	21	2	3
041B00 064N	6	234 .7	24	8	393	2	1	3	2	2	3
076B00 111N	7	272	20	8	191 0	3	1	11	8	2	2
105B00 144R	7	482	60	8	176 00	1	2	22	0	4	3
105B00 145R	7	172	16	8	176 00	3	1	6	7	3	3
013B00 082R	10	437	42	8	229 0	3	1	19	21	2	1
013B00 083R	10	567	32	8	361 5	3	1	16	32	3	2
041B00 061N	6	257	18	9	565	3	1	18	11	1	2
079B00 146N	1	296 .9	24	11	224 0	3	2	18	11	3	2
041B00 058N	6	382	30	11	611 0	1	2	42	0	4	3
084B00 051N	7	177	34	11	631	3	1	8	19	3	2
096B00 040N	6	200 .1	56	12	112 00	3	2	17	12	3	2
076B00 105R	7	286 .1	20	12	269 50	3	2	5	12	2	3
045B00 081N	9	272	16	12	590 0	3	1	44	35	3	3
041B00 052N	6	223	16	13	348 0	3	2	0	7	3	1

076B00 107N	7	252	30	13	154 00	3	1	12	17	1	3
059B00 104N	6	147 4.1	22	14	132 00	3	2	8	26	2	1
048B00 181N	11	59. 1	12	14	358 0	1	1	4	0	4	2
073B00 159L	1	205	40	15	469 5	3	2	17	41	3	3
094B00 041N	6	765 .1	36	16	280 0	1	1	11	0	4	3
070B00 076N	1	57. 1	14	17	329 0	3	1	4	8	3	1
009B00 068R	7	146	24	17	860 0	1	1	7	0	4	2
048B00 176N	11	329	12	17	238 0	3	1	7	12	3	3
060B00 076N	12	54	16	17	671 0	1	1	6	0	4	3
056B00 454R	5	402 .7	42	18	135 00	3	2	25	22	3	2
081B00 067N	9	766 .1	60	19	511 0	3	2	76	52	3	2
097B00 116N	10	284 .1	40	20	420 0	3	2	2	40	1	3
011B00 055N	7	240	24	22	337 0	3	2	21	10	3	3
061B00 095N	11	517	48	22	861 0	3	2	35	31	2	2
061B00 091R	11	303	26	25	665 0	2	1	14	22	3	3

039B00 039N	6	387	24	26	397 0	3	1	18	40	2	3
021B00 054N	6	42. 3	16	27	534	1	1	7	0	4	3
068B00 101N	9	294	24	28	290 0	3	1	22	42	2	3
021B00 049N	6	265 .1	24	31	534 0	3	1	15	50	3	2
041B00 038N	6	146	16	32	398 0	3	1	21	6	3	2
048B00 103N	11	302	24	39	637	3	1	42	22	2	1
048B00 124N	11	130	40	39	602 0	3	1	12	15	3	1
009B00 052L	7	244 .4	26	40	615 0	1	1	9	0	4	2
048B00 110N	11	369	44	40	595 0	3	1	14	13	3	1
048B00 118N	11	226	48	41	602 0	2	1	12	19	3	2
048B00 117N	11	300	48	41	602 0	2	1	23	12	3	3
067B00 081N	12	358 .9	48	41	919 0	3	1	16	22	2	3
111B00 027R	1	151 .9	42	42	955 0	1	1	12	0	4	2
048B00 114N	11	217	44	42	595 0	2	1	21	21	3	2
048B00 113N	11	208	44	42	595 0	3	1	9	14	3	3

037B00 053R	5	299 .8	89	43	190 50	3	1	12	15	2	2
052B00 037N	5	139 .2	19	45	139 0	3	1	12	21	3	2
039B00 010N	6	404 .9	28	45	272 0	3	1	12	11	1	2
022B00 084L	9	227	40	46	600 0	3	1	13	9	3	2
052B00 051L	5	434 .4	32	47	169 50	3	1	42	18	2	2
056B00 167R	5	274 .5	52	48	340 50	3	1	40	56	1	2
039B00 017N	6	293	24	48	352	3	1	10	22	2	2
039B00 030N	6	274	26	48	93	3	1	8	36	2	2
021B00 038L	6	336	30	48	146 00	3	1	30	14	2	3
039B00 023R	6	154 .9	40	48	136 00	2	1	31	9	2	3
021B00 037L	6	233 .9	40	48	136 00	3	1	28	60	3	3
022B00 088L	9	144	44	48	735 0	2	1	4	11	2	2
090B00 019L	4	330 .1	30	50	495 0	3	1	26	13	1	2
050B00 030L	4	194 .9	24	51	185 00	3	1	13	24	2	3
094B00 001N	6	43	28	53	208	1	1	4	0	4	3

118B00	11	200	20	52	127	2	1	15	20	2	1
059R	11	555	50	55	00	5	Т	15	25	2	1
118B00	11	347	30	53	127	3	1	15	32	3	1
058R		0.17	50	55	00	5	-	10	52	5	-
118B00	11	99	40	53	127	3	1	13	15	1	1
054R					00	Ū	_			_	_
041B00	6	254	32	54	694	З	1	20	18	2	1
007N		.8	01	0.	0	Ū	-			_	_
047B00	Д	317	30	57	182	2	1	0	44	2	2
036R		.9	50	57	00	-	-	Ŭ		-	-
108B00	5	407	28	57	486	3	1	25	25	2	3
010N	0	.4	20	57	0	5	-	20	20	-	5
039B00	6	65	26	59	376	1	1	12	0	Д	3
022N	U	0.5	20	35	570	-	-		Ŭ		5
067B00	12	317	36	64	291	3	1	15	13	3	3
027N		.9	50	01	0	5	-	10	10	5	5
049B00	6	265	26	66	142	1	2	23	0	4	1
021N	U	200	20	00	00	-	-	20	Ū		-
009B00	6	151	30	67	517	1	1	8	0	4	1
002N	U	.9	50	07	0	-	-	Ū	Ū		-
118B00	11	214	38	72	315	1	1	12	0	4	1
040N		.9			0	-	-		, C		_
048B00	11	160	20	77	326	1	1	13	0	4	2
012N					0	-	-		, C		
094B00	6	65.	20	79	244	1	1	8	0	4	2
002N	U	9	20	, ,		-	-	Ū	Ū		-
039B00	6	37	24	81	119	1	1	13	0	4	3
006N	5				0	-	-				
Bridge_I	Dist	Len	Wi	Арр		AbuT	АррТ	EmbH	FSoilD	Consist	Seve
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D	rict	gth	dth	Age	ADT	уре	уре	eight	epth	ency	rity
065B00 024N	10	133	28	30	110 6	3	1	0	36	2	1
077B00 084N	10	156	56	8	579 8	1	1	5	50	2	2
004B00 028N	1	693	28	73	163 1	3	1	13	26	2	1
004B00 061N	1	99	44	22	415 5	3	1	13	50	2	1
016B00 050N	3	130	22	60	232	3	1	13	50	2	1
018B00 020N	1	99	23	82	161 2	3	1	4	40	2	1
018B00 109N	1	115	22	58	768	3	1	8	39	2	1
018B00 115N	1	90	44	24	207 0	3	1	3	50	2	1
018B00 116N	1	90	44	24	207 0	3	1	3	50	2	1
020B00 024N	1	198	22	67	894	3	1	3	24	2	1
021B00 048N	6	211	30	31	840 0	3	1	13	45	2	1
021B00 050N	6	361	30	30	646 0	3	1	20	50	2	1
028B00 051N	1	157	20	53	120	3	1	12	36	2	1

Appendix D: Detailed Data Information of Sample Two

036B00 096N	12	203	44	36	307 0	3	1	13	50	2	1
038B00 011N	1	330	24	74	104 0	3	1	2	32	2	1
038B00 065N	1	99	24	56	81	3	1	2	41	2	1
038B00 078N	1	238	40	30	244 9	3	1	26	42	2	1
038B00 081N	1	71	44	27	205 0	3	1	6	50	2	1
042B00 031N	1	84	24	52	341	3	1	9	40	2	1
042B00 194N	1	99	24	51	235	3	1	2	40	2	1
042B00 195N	1	99	24	51	235	3	1	4	40	2	1
053B00 033N	1	114	24	56	118	3	1	11	50	2	1
053B00 047N	1	175	24	74	994	3	1	3	33	2	1
063B00 105N	11	34	22	15	411 62	3	1	0	14	2	1
065B00 026N	10	147	30	28	235 0	3	1	8	50	2	1
067B00 010N	12	237	44	45	842 7	3	1	31	19	2	1
072B00 020N	1	811	26	51	974	3	1	5	50	2	1
073B00 010N	1	389	28	51	230 0	3	1	27	50	2	1

073B00 048N	1	114	28	55	271 0	3	1	9	50	2	1
073B00 049N	1	132	28	55	277 4	3	1	10	50	2	1
073B00 108N	1	430	28	40	117 6	3	1	17	50	2	1
073B00 113N	1	337	44	40	311 9	3	1	10	20	2	1
073B00 114L	1	458	39	40	185 80	3	1	37	50	2	1
073B00 115R	1	143	39	40	185 80	3	1	6	50	2	1
073B00 116L	1	197	40	40	157 54	3	1	35	20	2	1
073B00 119L	1	172	40	40	157 54	3	1	45	15	2	1
073B00 121N	1	260	88	40	120 33	3	1	9	50	2	1
073B00 153N	1	214	30	16	375	3	1	3	12	2	1
079B00 013N	1	84	24	52	578	3	1	6	50	2	1
088B00 042N	10	186	30	52	469 0	3	1	20	13	2	1
097B00 089N	10	646	32	42	978 4	3	1	33	15	2	1
107B00 040N	3	173	44	14	416 5	3	1	27	41	2	1
111B00 045N	1	317	28	41	101 0	3	1	22	44	2	1

114B00 053R	3	220	30	43	632 2	3	1	0	20	2	1
004B00 027N	1	300	24	73	127 7	3	1	1	30	2	2
008B00 051N	6	234	44	43	820 7	3	1	18	50	2	2
008B00 066N	6	305	54	30	683 72	3	1	4	50	2	2
016B00 016N	3	264	24	80	263 0	3	1	12	50	2	2
019B00 066N	6	93	82	25	975 7	3	1	11	42	2	2
021B00 039R	6	336	30	48	146 00	3	1	4	10	2	2
021B00 058N	6	275	32	9	917	3	1	22	50	2	2
022B00 132N	9	63	28	31	673	3	1	0	27	2	2
034B00 039L	7	159	30	53	318 15	3	1	22	11	2	2
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053B00 021N	1	198	30	67	894	3	1	4	24	2	2
056B00 146L	5	72	29	45	275 9	3	1	23	9	2	2
058B00 044N	12	99	26	73	984	3	1	12	40	2	2
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073B00 015N	1	66	22	46	137 9	3	1	14	50	2	2
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079B00 017N	1	99	19	77	315 2	3	1	12	16	2	2
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079B00 146N	1	297	48	11	232 7	3	1	4	50	2	2
097B00 017L	10	265	30	46	126 00	3	1	24	13	2	2
097B00 105N	10	302	86	33	216 00	3	1	21	32	2	2
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056B00 251N	5	188	142	45	599 00	3	1	40	50	2	3
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081B00 068N	9	157	35	16	163 1	3	1	5	50	2	3
087B00 015N	7	165	20	61	128 1	3	1	11	17	2	3
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106B00 066L	5	195	30	55	190 78	3	1	22	23	2	3
036B00 084L	12	562	28	52	705 1	2	1	15	20	2	2
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079B00 076L	1	519	30	48	864 0	3	2	12	50	2	1
080B00 022N	12	312	42	29	567 3	3	2	22	25	2	1
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007B00 109N	11	326	28	32	697	3	2	6	34	2	2
018B00 119N	1	75	46	22	744	3	2	13	39	2	2
019B00 064N	6	77	26	27	104 720	3	2	0	38	2	2
028B00 052N	1	224	34	38	517	3	2	0	47	2	2
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048B00 140N	11	189	24	35	117 4	3	2	8	20	2	3
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108B00 037N	5	323	278	31	676	3	2	14	32	2	3
113B00 102N	2	173	39	18	175 3	3	2	3	17	2	3
004B00 057N	1	90	40	30	687 1	1	1	0	0	4	1
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021B00 023N	6	34	23	85	161 0	1	1	7	0	4	1
028B00 013N	1	212	19	82	741	1	1	9	0	4	1
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034B00	7	57	54	16	497	1	1	13	0	4	1
154N					3						
036B00	12	200	24	5	219	1	1	24	0	4	1
152N					2						
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031N	12	40	20	57		-	-	10	U	-	-
064B00	12	20	20	10	00	1	1	2	0	4	1
083N	12	38	29	18	90	T	T	Z	0	4	T
067B00	17	00	22	67	133	1	1	л	0	4	1
046N	12	33	22	07	4	T	T	4	0	4	T
070B00	1	02	70	22	617	1	1	0	0	4	1
068N	1 I	65	20	55	017	T	T	0	0	4	T
073B00	1	250	4.4	40	438	1	1	12	0	4	1
122N	T	256	44	40	5	T	T	12	U	4	T
076B00	7	40	42	15	376	1	1	12	0	4	1
100N	/	40	45	12	0	T	T	15	0	4	T
076B00	7	100	20	14	600	1	1	10	0	4	1
101N	/	100	29	14	000	T	T	10	0	4	T
079B00	1	67	23	83	266	1	1	5	0	л	1
037N	1	07	25	05	7	T	Т	5	0	4	Т
083B00	10	69	27	13	475	1	1	0	0	4	1
039N	10	05	27	15	475	T	T	0	U	-	T
086B00	2	20	20	61	707	1	1	c	0	4	1
032N	5	58	20	01	/8/	T	T	D	0	4	T
087B00	7	66	26	20	449	1	1	0	0	4	1
008N	/	00	20	28	0	T	T	0	0	4	T
091B00	0	121	40	10	391	1	1	0	0	A	1
062N	9	131	48	13	0	T	T	0	0	4	T
095B00	10	66	20	76	797	1	1	л	Ο	л	1
003N	10		20	,0	, 0,	-	-	-		-	-

097B00 012L	10	504	30	46	641 8	1	1	0	0	4	1
097B00 042N	10	261	26	54	706	1	1	11	0	4	1
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003B00 059N	7	37	33	11	277 0	1	1	12	0	4	2
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034B00 010N	7	443	16	60	137 0	1	1	20	0	4	2
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042B00 274N	1	134	65	12	931 4	1	1	2	0	4	2
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049B00 027N	6	34	14	79	679	1	1	4	0	4	2
049B00 036N	6	78	19	83	761	1	1	7	0	4	2
052B00 056N	5	63	23	40	128 5	1	1	0	13	4	2
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066B00 033N	11	124	24	63	245 0	1	1	10	0	4	2
067B00 031N	12	116	19	82	714	1	1	8	0	4	2

072B00 005N	1	62	19	83	445	1	1	7	0	4	2
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073B00 026N	1	43	28	60	681 0	1	1	2	0	4	2
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077B00 085N	10	224	44	8	136 4	1	1	17	0	4	2
079B00 035N	1	129	23	83	136 0	1	1	4	0	4	2
079B00 047N	1	172	19	83	119 7	1	1	4	0	4	2
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086B00 056N	3	92	40	11	276 0	1	1	15	0	4	2
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118B00 022N	11	140	20	83	251 9	1	1	12	0	4	2
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007B00 062N	11	60	18	54	813	1	1	19	0	4	3
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034B00 123N	7	204	68	34	163 17	1	1	27	0	4	3
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040B00 028L	7	109 8	40	41	975 0	1	1	14	0	4	3
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105B00 046N	7	63	23	45	483	1	1	12	0	4	3
003B00 007R	7	108 8	30	50	864 3	3	1	50	0	4	2
019B00 044L	6	283	66	41	295 52	3	1	40	0	4	2
019B00 045N	6	494	25	41	591 03	3	1	50	0	4	2
057B00 012N	7	185	24	51	146 0	3	1	15	0	4	2
103B00 056L	9	156	40	47	600 0	3	1	50	0	4	2
019B00 048L	6	285	52	44	440 75	3	1	50	0	4	3
034B00 032L	7	159	30	53	318 14	3	1	38	0	4	3
067B00 008N	12	205	30	50	723 2	3	1	7	0	4	3
063B00 025N	11	132	26	73	133 01	2	1	6	0	4	3

002B00 012N	3	225	30	50	345 0	2	1	14	0	4	1
005B00 047N	3	100	20	62	204	2	1	6	0	4	1
012B00 017N	6	152	20	60	260	2	1	6	0	4	1
033B00 015N	10	189	24	56	546	2	1	5	0	4	1
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060B00 060N	12	231	25	45	801	2	1	5	0	4	1
061B00 049N	11	76	22	66	130	2	1	5	0	4	1
067B00 097N	12	67	40	35	118 5	2	1	12	0	4	1
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111B00 060N	1	448	39	6	704	2	1	0	0	4	1
005B00 095R	3	289	42	13	187 5	2	1	10	0	4	2
008B00 026N	6	66	22	62	155 7	2	1	4	0	4	2
008B00 032N	6	279	26	48	183 0	2	1	0	0	4	2
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008B00 042L	6	307	22	48	907 93	2	1	18	0	4	2

008B00 078L	6	159	73	22	453 97	2	1	12	0	4	2
008B00 080L	6	159	73	23	585 71	2	1	4	0	4	2
010B00 073L	9	246	42	8	958 0	2	1	8	0	4	2
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028B00 029N	1	89	20	65	74	2	1	4	0	4	2
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041B00 014N	6	321	24	82	145 0	2	1	8	0	4	2
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055B00 020N	11	101	20	65	315	2	1	9	0	4	2
063B00 002N	11	252	24	74	696 7	2	1	19	0	4	2

066B00 013N	11	212	21	71	308 0	2	1	10	0	4	2
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096B00 001N	6	630	24	79	284 1	2	1	6	0	4	2
096B00 008N	6	133	26	4	285 1	2	1	16	0	4	2
096B00 026N	6	159	22	61	115 3	2	1	7	0	4	2
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106B00 062L	5	245	30	55	272 28	2	1	15	0	4	2
110B00 011N	3	121	28	83	349 7	2	1	3	0	4	2
114B00 005N	3	200	54	61	222 69	2	1	25	0	4	2
118B00 044N	11	530	26	65	101 00	2	1	30	0	4	2
118B00 046L	11	172	38	48	182 50	2	1	13	0	4	2
118B00 090N	11	192	26	67	117 73	2	1	0	0	4	2
003B00 022N	7	236	26	50	120 67	2	1	11	0	4	3

009B00 008N	7	129	20	76	132 0	2	1	12	0	4	3
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011B00 047N	9	70	26	32	777 0	2	1	6	0	4	3
019B00 030N	6	114	24	60	360 0	2	1	5	0	4	3
028B00 024N	1	198	14	67	198	2	1	3	0	4	3
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034B00 021L	7	134	24	53	318 14	2	1	18	0	4	3
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034B00 078R	7	132	50	51	256 48	2	1	20	0	4	3
037B00 060R	5	213	30	55	183 50	2	1	30	0	4	3
041B00 011N	6	241	24	82	343 0	2	1	12	0	4	3
045B00 025N	9	225	25	73	154 6	2	1	14	0	4	3
056B00 369N	5	282	84	29	100 98	2	1	11	0	4	3
061B00 084N	11	79	28	32	207 0	2	1	27	0	4	3
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071B00 047N	3	364	24	79	800 3	2	1	26	0	4	3
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026B00 0108N	11	144	40	22	130 35	1	2	11	0	4	1
026B00 109N	11	63	32	22	379	1	2	9	0	4	1
028B00 058N	1	36	41	31	400 0	1	2	18	0	4	1
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059B00 098N	6	247	28	17	340	1	2	0	0	4	1
060B00 058N	12	341	33	43	536 8	1	2	50	0	4	1
063B00 110N	11	115	28	16	670	1	2	5	0	4	1
064B00 066N	12	240	30	31	566	1	2	0	0	4	1
067B00 111N	12	142	30	30	282 5	1	2	6	0	4	1
067B00 122N	12	213	33	23	778	1	2	4	0	4	1
076B00 089N	7	53	28	22	583	1	2	9	0	4	1
098B00 239N	12	108	30	17	576 0	1	2	10	0	4	1

110B00 040L	3	83	42	17	244 0	1	2	4	0	4	1
025B00 100N	7	87	40	20	473 3	1	2	17	0	4	2
028B00 063N	1	73	44	26	318 0	1	2	10	0	4	2
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105B00 142R	7	78	42	8	515 0	1	2	8	0	4	2
008B00 009N	6	276	82	55	524 58	1	2	0	0	4	3
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041B00 047N	6	219	65	17	297 00	1	2	3	0	4	3
056B00 393N	5	99	149	27	171 000	1	2	0	0	4	3
093B00 049N	5	92	29	29	235 6	1	2	7	0	4	3

118B00	11	485	30	57	162	3	2	40	0	4	2
070800					392						
075N	1	71	44	22	7	2	2	3	0	4	2
086B00 053N	3	140	32	19	276 0	2	2	5	0	4	2
103B00 077N	9	149	30	27	555 0	2	2	11	0	4	2
105B00 107R	7	296	47	28	117 53	2	2	5	0	4	2
105B00 108R	7	358	62	27	115 08	2	2	13	0	4	2
022B00 075N	9	185	11. 2	51	192 1	1	1	20	0	3	3
053B00 059N	1	231	24	60	275	3	1	10	50	3	1
040B00 004N	7	154	20	67	277 0	3	1	3	21	3	3
042B00 118N	1	99	23	81	775	1	1	6	0	3	1
042B00 093N	1	38	28	59	516 0	1	1	8	40	3	2
007B00 101N	11	96	23	37	119 1	1	1	20	0	3	3
002B00 009N	3	363	26	52	197	3	1	24	41	3	1
004B00 039N	1	99	24	57	254	3	1	5	40	3	1
004B00 051N	1	99	24	55	240	3	1	5	50	3	1

013B00 039N	10	406	24	56	141 0	3	1	25	24	3	1
018B00 102N	1	365	44	32	919 8	3	1	17	50	3	1
018B00 122N	1	54	22	18	392	3	1	10	12	3	1
018B00 124N	1	58	22	18	54	3	1	10	12	3	1
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028B00 049N	1	114	24	55	294	3	1	7	49	3	1
036B00 110N	12	798	44	37	218 3	3	1	20	13	3	1
036B00 125N	12	192	30	27	199	3	1	4	50	3	1
036B00 153N	12	200	24	5	219 2	3	1	12	23	3	1
038B00 015N	1	196	38	48	173 0	3	1	22	50	3	1
038B00 048N	1	159	22	44	40	3	1	3	20	3	1
038B00 084N	1	78	26	22	93	3	1	8	48	3	1
042B00 028N	1	208	26	48	341	3	1	23	50	3	1
042B00 057N	1	84	26	56	825	3	1	3	40	3	1
042B00 129N	1	114	24	56	673	3	1	3	50	3	1

042B00 172N	1	241	26	48	200	3	1	20	38	3	1
042B00 196N	1	114	24	55	730	3	1	4	49	3	1
042B00 222N	1	180	28	28	233 8	3	1	5	50	3	1
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042B00 261N	1	71	29	16	419	3	1	0	21	3	1
053B00 036N	1	87	19	83	130	3	1	12	40	3	1
053B00 098N	1	227	26	18	239	3	1	0	23	3	1
053B00 100N	1	212	28	16	140	3	1	2	28	3	1
059B00 053L	6	256	62	21	961 77	3	1	0	10	3	1
067B00 038N	12	411	20	75	778	3	1	0	32	3	1
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067B00 102N	12	149	77	36	137 54	3	1	10	20	3	1
067B00 103N	12	291	44	36	137 54	3	1	10	20	3	1
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073B00 101L	1	133	38	43	140 45	3	1	23	50	3	1
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079B00 089N	1	132	24	60	504	3	1	7	41	3	1
079B00 144R	1	232	28	16	419 0	3	1	9	11	3	1
097B00 100N	10	288	82	34	924 3	3	1	10	10	3	1
098B00 201R	12	157	45	37	169 69	3	1	8	17	3	1
006B00 050R	9	157	40	48	807 1	3	1	13	7	3	2
007B00 121N	11	208	30	27	185 4	3	1	0	37	3	2
010B00 074N	9	293	29	8	156 21	3	1	10	45	3	2
016B00 019N	3	76	24	77	147	3	1	8	20	3	2
018B00 090N	1	99	24	52	277	3	1	5	37	3	2
018B00 126N	1	163	34	11	139 3	3	1	0	50	3	2
028B00 048N	1	99	24	55	79	3	1	4	23	3	2
034B00 158N	7	262	56	12	439 7	3	1	3	26	3	2

035B00 097N	9	266	54	9	286 2	3	1	31	8	3	2
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036B00 107N	12	235	82	37	120 22	3	1	28	20	3	2
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036B00 114N	12	187	70	37	119 70	3	1	23	47	3	2
036B00 139N	12	105	84	15	113 82	3	1	8	10	3	2
036B00 140N	12	250	86	15	113 82	3	1	2	22	3	2
042B00 009N	1	213	30	48	328 0	3	1	15	40	3	2
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053B00 014N	1	132	20	78	765	3	1	8	30	3	2
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056B00 153N	5	220	38	49	776 04	3	1	25	50	3	2
058B00 041N	12	827	30	53	620 4	3	1	2	50	3	2
058B00 050R	12	129	44	46	565 0	3	1	20	34	3	2
059B00 106L	6	479	40	13	894 8	3	1	18	7	3	2
059B00 108N	6	279	85	14	178 96	3	1	7	6	3	2
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061B00 082R	11	225	40	36	935 0	3	1	7	43	3	2
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073B00 009N	1	294	44	43	780 0	3	1	11	50	3	2
073B00 059N	1	204	42	55	805 0	3	1	0	41	3	2
073B00 079N	1	132	24	63	343 5	3	1	10	40	3	2
073B00 093N	1	238	50	64	163 64	3	1	30	40	3	2

079B00	1	152	30	54	326	3	1	11	50	3	2
011N					2						
079800	1	114	28	47	235	3	1	11	39	3	2
079800		210			131						
118R	1	8	39	41	55	3	1	40	50	3	2
080800		0			156						
013N	12	200	24	57	0	3	1	6	50	3	2
080B00	12	99	24	50	184	3	1	0	50	3	2
018N	12	55	27	50	0	5	-	Ū	50	5	-
088B00	10	84	20	78	200	3	1	4	26	3	2
010N					0)	_			Ū	_
103B00	9	303	76	9	222	3	1	18	27	3	2
093N					00						
105B00	7	171	40	16	459	3	1	3	5	3	2
133N					0						
114B00	3	283	120	13	463	3	1	2	12	3	2
087N					60						
114B00	3	128	59	13	213	3	1	1	12	3	2
090R					80						
118B00	11	674	30	50	154	3	1	32	39	3	2
045L					96						
120B00	7	165	39	42	194	3	1	20	20	3	2
024L					00						
007B00	11	99	31	16	156	3	1	2	11	3	3
143N											
008B00	6	318	30	57	196	3	1	25	50	3	3
021N					6						
008800	6	640	26	25	133	3	1	32	18	3	3
073N					930						

011B00	7	509	44	44	114	3	1	39	3	3	3
038L					00						
018B00	1	345	42	6	193	3	1	6	13	3	3
137R					6						
035B00	9	95	30	12	148	3	1	2	8	3	3
091N										-	
036B00	12	114	ЛЛ	51	116	r	1	20	30	3	R
021N	12	114		51	00	5	T	20	50	5	5
036B00	12	00	28	56	198	2	1	15	50	2	2
036N	12	55	20	50	9	5	Т	15	50	5	5
036B00	12	271	24	E2	274	2	1	0	50	2	2
078N	12	5/1	24	22	0	5	T	0	50	5	5
036B00	12	0.0	26	10	600	2	1	0	1.4	2	2
138N	12	98	20	19	600	5	T	0	14	5	3
040B00	-	150	20	1.4	410	2	1	11	20	2	2
038N	/	122	30	14	412	5	T	11	30	5	3
045B00	_	226	40	12	520	2	1	_	-	2	2
077N	9	230	48	12	9	3	T	/	5	3	3
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156L	5	204	50	45	44	5	Т	22	50	5	5
056B00	5	385	30	49	148	3	1	38	50	3	2
158N	5	505	50	75	888	5	-	50	50	5	5
056B00	E	151	40	1 0	322	2	1	10	0	2	2
372R	5	131	40	20	85	5	T	10	9	5	5
057B00	-	120	20	1.4	441	2	1	4	0	2	2
031N	/	120	20	14	0	Э	T	4	9	5	5
059B00	E	150	QO	55	776	2	1	20	16	2	2
038L	0	139	00	55	69	5	T	50	40	5	5
064B00	12	201	21	27	181	3	1	15	50	2	2
063N		201	54	52	-04	5	т	15	50		5

073B00 061N	1	214	30	55	195 00	3	1	0	50	3	3
079B00 114R	1	193	47	39	130 00	3	1	24	11	3	3
081B00 036N	9	210	26	52	109 1	3	1	32	49	3	3
084B00 046N	7	172	35	15	698	3	1	2	6	3	3
087B00 059N	7	354	40	18	685 4	3	1	12	5	3	3
100B00 029N	8	120 8	26	64	586 4	3	1	0	12	3	3
114B00 085L	3	496	41	13	787 5	3	1	7	6	3	3
118B00 056R	11	141	38	50	127 00	3	1	30	5	3	3
004B00 067N	1	90	23	13	325	2	1	3	0	3	2
034B00 094L	7	117	62	51	387 54	2	1	5	4	3	2
012B00 030N	6	244	44	26	483 3	3	2	22	18	3	1
013B00 071N	10	122	24	27	206	3	2	9	18	3	1
021B00 034N	6	150	24	45	291	3	2	7	17	3	1
028B00 064N	1	41	45	26	171 0	3	2	10	33	3	1
041B00 041N	6	403	24	26	121	3	2	10	30	3	1

042B00 159L	1	97	38	48	380 5	3	2	12	40	3	1
042B00 217N	1	245	28	31	691	3	2	0	34	3	1
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042B00 254N	1	70	30	17	877	3	2	0	16	3	1
060B00 056N	12	633	32	43	619 1	3	2	38	4	3	1
060B00 070N	12	168	32	27	112 5	3	2	10	18	3	1
070B00 046N	1	216	30	46	313 0	3	2	47	50	3	1
071B00 097L	3	204	43	20	173 1	3	2	14	15	3	1
073B00 064N	1	228	27	44	386	3	2	20	50	3	1
073B00 138N	1	140	31	31	112 00	3	2	17	48	3	1
076B00 099N	7	93	93	17	341 00	3	2	2	6	3	1
079B00 128N	1	223	40	29	884 2	3	2	13	50	3	1
079B00 135N	1	51	28	22	255	3	2	7	45	3	1
088B00 072N	10	141	46	33	685 0	3	2	15	18	3	1
088B00	10	252	40	24	255	3	2	3	23	3	1
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081N	10	202	.0		0)	1	5		5	-
098B00	12	289	28	29	182	3	2	15	16	3	1
186N					0	0	_				_
119B00	10	74	40	19	150	з	2	3	25	3	1
062N	10		10	10	7	5	-	5	20	5	-
015B00	5	289	24	29	50	r	2	18	6	3	2
071N	5	205	27	25	50	5	2	10	0	5	2
030B00	2	206	86	18	146	a	2	8	50	3	2
155N	2	200	00	10	80	5	2	0	50	5	2
034B00	7	195	43	11	772	з	2	18	16	3	2
164L	,	155	15		8	5	-	10	10	5	-
042B00	1	208	24	48	740	з	2	26	50	3	2
154R	-	200	21	10	0	5	-	20	50	5	-
042B00	1	189	38	48	320	r	2	14	40	3	2
162R	-	105	50	-10	5	5	2	14	40	5	2
042B00	1	97	38	48	320	ч	2	12	50	3	2
163L	-	57	50	10	5	5	-		50	5	-
042B00	1	97	38	48	320	3	2	13	50	3	2
165L	-	57	50	10	5	5	-	10	50	5	-
042B00	1	208	38	48	320	3	2	9	50	3	2
166R	-	200	50	10	5	5	-	5	50	5	-
042B00	1	310	30	48	377	3	2	16	50	3	2
170R	-	510		10	5	5	-	10	50	5	-
042B00	1	67	39	16	237	ч	2	0	19	3	2
257N	-	07	55	10	9	5	-	Ŭ	15	5	-
045B00	9	464	60	12	520	3	2	20	30	3	2
082N					9	,					
049B00	6	310	52	20	474	3	2	6	34	3	2
068N					0	5	-				-

058B00 058N	12	190	44	37	771 5	3	2	15	36	3	2
058B00 064N	12	134	32	32	106 00	3	2	8	27	3	2
058B00 068N	12	83	41	25	115 0	3	2	6	15	3	2
066B00 061N	11	324	30	29	288 0	3	2	16	20	3	2
098B00 196N	12	142	40	27	518 0	3	2	4	35	3	2
107B00 035N	3	170	76	31	323 8	3	2	27	28	3	2
021B00 045N	6	259	44	41	142 00	3	2	19	36	3	3
022B00 083R	9	357	38	44	101 23	3	2	16	47	3	3
041B00 048N	6	290	41	14	115 00	3	2	4	7	3	3
047B00 156N	4	303	44	19	555 9	3	2	44	14	3	3
056B00 426L	5	103 0	85	26	585 00	3	2	32	41	3	3
120B00 038N	7	182	25	21	171 0	3	2	13	10	3	3
018B00 024N	1	87	23	70	272 0	3	1	7	30	1	1
042B00 201N	1	159	23	38	207	3	1	0	50	1	1
059B00 081L	6	547	36	32	753 7	3	1	10	50	1	1

064B00 058N	12	93	34	36	457	3	1	9	39	1	1
067B00 083N	12	343	62	41	941 6	3	1	37	7	1	1
070B00 065N	1	146 7	25	63	679 4	3	1	7	50	1	1
080B00 039N	12	164	33	16	385	3	1	0	21	1	1
097B00 056N	10	159	36	48	966 3	3	1	20	19	1	1
111B00 043N	1	262	27	42	61	3	1	27	28	1	1
003B00 060N	7	254	133	12	148 00	3	1	14	11	1	2
012B00 008N	6	159	26	54	826	3	1	22	40	1	2
026B00 061N	11	178	76	44	117 24	3	1	27	7	1	2
032B00 012N	9	114	24	65	250	3	1	2	40	1	2
033B00 019N	10	165	22	80	157 0	3	1	5	30	1	2
036B00 037L	12	308	45	42	985 0	3	1	24	50	1	2
036B00 077N	12	246	30	53	593 0	3	1	0	50	1	2
042B00 128N	1	215	26	48	673	3	1	25	50	1	2
053B00 022N	1	185	24	74	132 0	3	1	6	48	1	2

059B00 073N	6	207	40	37	260 3	3	1	28	9	1	2
064B00 018N	12	121	20	78	808	3	1	4	34	1	2
079B00 023N	1	349 6	20	83	220 0	3	1	10	30	1	2
098B00 256L	12	127 6	42	9	735 0	3	1	50	20	1	2
036B00 008N	12	84	30	60	289 0	3	1	2	30	1	3
036B00 086N	12	358	28	52	127 0	3	1	30	50	1	3
051B00 073R	2	191	26	45	500 0	3	1	27	34	1	3
051B00 074N	2	270	34	45	461 0	3	1	23	33	1	3
051B00 076N	2	240	30	45	672	3	1	22	38	1	3
054B00 012R	2	174	38	47	633 7	3	1	30	21	1	3
084B00 014R	7	200	30	50	525 0	3	1	20	14	1	3
018B00 120N	1	140	44	19	686 1	3	2	7	50	1	1
019B00 067N	6	165	82	26	975 7	3	2	17	40	1	1
053B00 050N	1	222	28	48	278	3	2	16	50	1	1
042B00 177L	1	211	38	48	435 5	3	2	9	48	1	2

052B00 075N	5	175	27	26	362	3	2	24	12	1	2
0751											
056B00	5	170	46	17	182	З	2	36	7	1	2
314L	5	170	40	17	50	5	2	50	,	Т	2

Appendix E: Output of the Ordinal Logistic Regression for Sample One

GET FILE='C:\Users\jzh252\Desktop\Samplel.sav'. DATASET NAME DataSet1 WINDOW=FRONT. PLUM SEVERITY BY DISTRICT ABUT APPT FSC WITH LENGTH WIDTH AGE ADT EH FSD /CRITERIA=CIN(95) DELTA(0) LCONVERGE(0) MXITER(100) MXSTEP(5) PCONVERGE(1.0E-6) SINGULAR(1.0E-8) /LINK=LOGIT /PRINT=FIT PARAMETER SUMMARY TPARALLEL.

PLUM - Ordinal Regression

Warnings

There are 174 (66.7%) cells (i.e., dependent variable levels by observed combinations of predictor variable values) with zero frequencies.

Unexpected singularities in the Fisher Information matrix are encountered. There may be a quasi-complete separation in the data. Some parameter estimates will tend to infinity.

The PLUM procedure continues despite the above warning(s). Subsequent results shown

are based on the last iteration. Validity of the model fit is uncertain.

			Marginal
		Ν	Percentage
SEVERITY	1.00	14	16.1%
	2.00	36	41.4%
	3.00	37	42.5%
DISTRICT	1.00	4	4.6%
	4.00	4	4.6%
	5.00	11	12.6%
	6.00	30	34.5%
	7.00	9	10.3%
	9.00	5	5.7%
	10.00	3	3.4%
	11.00	18	20.7%
	12.00	3	3.4%
ABUT	1.00	18	20.7%
	2.00	10	11.5%
	3.00	59	67.8%
APPT	1.00	70	80.5%

Case Processing Summary

	2.00	17	19.5%
FSC	1.00	7	8.0%
	2.00	31	35.6%
	3.00	30	34.5%
	4.00	19	21.8%
Valid		87	100.0%
Missing		0	
Total		87	

Model Fitting Information

	-2 Log			
Model	Likelihood	Chi-Square	df	Sig.
Intercept Only	177.953			
Final	147.035	30.918	20	.056

Link function: Logit.

Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	154.849	152	.421
Deviance	147.035	152	.599

Link function: Logit.

Pseudo R-Square Cox and Snell .299 Nagelkerke .344 McFadden .174

Link function: Logit.

Parameter Estimates

						95% Confide	ence Interval
		Std.				Lower	Upper
	Estimate	Error	Wald	df	Sig.	Bound	Bound
Threshold [SEVERITY = 1.00]	-22.103	2.653	69.404	1	.000	-27.303	-16.903

	[SEVERITY = 2.00]	-19.557	2.661	54.024	1	.000	-24.772	-14.342
Location	LENGTH	003	.001	4.263	1	.039	005	.000
	WIDTH	.000	.020	.000	1	.988	039	.038
	AGE	050	.015	10.820	1	.001	079	020
	ADT	-4.102E- 5	2.284E- 5	3.226	1	.072	-8.578E-5	3.739E-6
	EH	.024	.024	1.009	1	.315	022	.070
	FSD	.028	.022	1.641	1	.200	015	.070
	[DISTRICT=1.00]	-22.056	1.145	370.988	1	.000	-24.300	-19.812
	[DISTRICT=4.00]	-19.315	1.194	261.665	1	.000	-21.655	-16.975
	[DISTRICT=5.00]	-20.446	1.018	403.198	1	.000	-22.442	-18.451
	[DISTRICT=6.00]	-20.195	.662	931.737	1	.000	-21.492	-18.899
	[DISTRICT=7.00]	-20.271	.926	478.701	1	.000	-22.086	-18.455
	[DISTRICT=9.00]	-20.858	1.069	380.390	1	.000	-22.954	-18.762
	[DISTRICT=10.00]	-22.022	1.335	271.945	1	.000	-24.639	-19.405
	[DISTRICT=11.00]	-21.657	.000		1		-21.657	-21.657
	[DISTRICT=12.00]	0 ^a			0			
	[ABUT=1.00]	3.555	2.474	2.065	1	.151	-1.293	8.404
	[ABUT=2.00]	1.646	.849	3.756	1	.053	019	3.311
	[ABUT=3.00]	0 ^a			0			
	[APPT=1.00]	348	.678	.264	1	.607	-1.678	.981
	[APPT=2.00]	0 ^a			0			
	[FSC=1.00]	2.226	2.483	.803	1	.370	-2.641	7.093
	[FSC=2.00]	2.502	2.329	1.154	1	.283	-2.062	7.067
	[FSC=3.00]	2.151	2.328	.854	1	.355	-2.412	6.714
	[FSC=4.00]	0 ^a			0			

Link function: Logit.

a. This parameter is set to zero because it is redundant.

The null hypothesis states that the location parameters (slope coefficients) are the same across response categories.

a. Link function: Logit.

b. The log-likelihood value cannot be further increased after maximum number of step-halving.

c. The Chi-Square statistic is computed based on the log-likelihood value of the last iteration of the general model. Validity of the test is uncertain.

Appendix F: Output of the Multinomial Logistic Regression for Sample One

NOMREG SEVERITY (BASE=LAST ORDER=ASCENDING) BY DISTRICT ABUT APPT FSC WITH LENGTH WIDTH AGE ADT EH FSD /CRITERIA CIN(95) DELTA(0) MXITER(100) MXSTEP(5) CHKSEP(20) LCONVERGE(0) PCONVERGE(0.000001) SINGULAR(0.00000001) /MODEL /STEPWISE=PIN(.05) POUT(0.1) MINEFFECT(0) RULE(SINGLE) ENTRYMETHOD(LR) REMOVALMETHOD(LR) /INTERCEPT=INCLUDE /PRINT=CLASSTABLE FIT PARAMETER SUMMARY LRT CPS STEP MFI IC.

Nominal Regression

Warnings

There are 174 (66.7%) cells (i.e., dependent variable levels by subpopulations) with zero frequencies.

Unexpected singularities in the Hessian matrix are encountered. This indicates that either

some predictor variables should be excluded or some categories should be merged.

The NOMREG procedure continues despite the above warning(s). Subsequent results

shown are based on the last iteration. Validity of the model fit is uncertain.

			Marginal
		Ν	Percentage
SEVERITY	1.00	14	16.1%
	2.00	36	41.4%
	3.00	37	42.5%
DISTRICT	1.00	4	4.6%
	4.00	4	4.6%
	5.00	11	12.6%
	6.00	30	34.5%
	7.00	9	10.3%
	9.00	5	5.7%
	10.00	3	3.4%
	11.00	18	20.7%
	12.00	3	3.4%
ABUT	1.00	18	20.7%
	2.00	10	11.5%
	3.00	59	67.8%

Case Processing Summary

APPT	1.00	70	80.5%
	2.00	17	19.5%
FSC	1.00	7	8.0%
	2.00	31	35.6%
	3.00	30	34.5%
	4.00	19	21.8%
Valid		87	100.0%
Missing		0	
Total		87	
Subpopul	ation	87 ^a	

a. The dependent variable has only one value

observed in 87 (100.0%) subpopulations.

	N	lodel Fitting	Criteria	Likelihood Ratio Tests			
		-2 Log					
Model	AIC	BIC	Likelihood	Chi-Square	df	Sig.	
Intercept Only	181.953	186.885	177.953				
Final	199.383	302.951	115.383	62.570	40	.013	

Model Fitting Information

Goodness-of-Fit							
-	Chi-Square	df	Sig.				
Pearson	120.916	132	.746				
Deviance	115.383	132	.848				

Pseudo R-Square							
Cox and Snell	.513						
Nagelkerke	.589						
McFadden	.352						

	Ν	Nodel Fitting Criteri	Likelih	ood Ratio Te	ests	
			-2 Log			
	AIC of Reduced	BIC of Reduced	Likelihood of			
Effect	Model	Model	Reduced Model	Chi-Square	df	Sig.
Intercept	199.383	302.951	115.383 ^a	.000	0	
LENGTH	197.334	295.970	117.334	1.950	2	.377
WIDTH	196.110	294.746	116.110	.727	2	.695
AGE	209.661	308.297	129.661	14.278	2	.001
ADT	197.052	295.689	117.052	1.669	2	.434
EH	197.560	296.196	117.560	2.176	2	.337
FSD	201.448	300.084	121.448	6.065	2	.048
DISTRICT	204.321	268.434	152.321	36.938	16	.002
ABUT	196.157	289.861	120.157	4.773	4	.311
APPT	198.496	297.133	118.496	3.113	2	.211
FSC	191.905	280.677	119.905	4.521	6	.606

Likelihood Ratio Tests

The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model.

The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.

							95% Co Interval f	onfidence or Exp(B)
		Std.					Lower	Upper
SEVERITY ^a	В	Error	Wald	df	Sig.	Exp(B)	Bound	Bound
1.00 Intercept	11.264	2463.658	.000	1	.996			
LENGTH	.003	.002	1.663	1	.197	1.003	.998	1.007
WIDTH	013	.058	.047	1	.829	.988	.881	1.107
AGE	.131	.048	7.457	1	.006	1.140	1.038	1.252
ADT	.000	.000	1.870	1	.172	1.000	1.000	1.000
EH	084	.063	1.809	1	.179	.919	.813	1.039
FSD	175	.091	3.709	1	.054	.839	.702	1.003
[DISTRICT=1.00]	21.483	2463.657	.000	1	.993	2137345651.087	.000	. ^b
[DISTRICT=4.00]	1.767	3096.612	.000	1	1.000	5.852	.000	. ^b
[DISTRICT=5.00]	3.722	2894.902	.000	1	.999	41.327	.000	.b

Parameter Estimates

		-							
	[DISTRICT=6.00]	17.908	2463.656	.000	1	.994	59907624.950	.000	. ^b
	[DISTRICT=7.00]	1.751	2717.319	.000	1	.999	5.758	.000	. ^b
	[DISTRICT=9.00]	4.132	2913.733	.000	1	.999	62.309	.000	. ^b
	[DISTRICT=10.00]	24.518	2463.658	.000	1	.992	44467382271.204	.000	. ^b
	[DISTRICT=11.00]	20.706	2463.656	.000	1	.993	982595954.472	.000	.b
	[DISTRICT=12.00]	0 ^c			0				
	[ABUT=1.00]	- 37.279	2.821	174.608	1	.000	6.457E-17	2.563E- 19	1.627E- 14
	[ABUT=2.00]	- 16.258	1288.134	.000	1	.990	8.695E-8	.000	.b
	[ABUT=3.00]	0 ^c			0				
	[APPT=1.00]	-1.622	1.493	1.181	1	.277	.197	.011	3.681
	[APPT=2.00]	0 ^c			0				
	[FSC=1.00]	- 32.712	2.060	252.053	1	.000	6.212E-15	1.095E- 16	3.525E- 13
	[FSC=2.00]	- 29.828	1.434	432.457	1	.000	1.111E-13	6.680E- 15	1.848E- 12
	[FSC=3.00]	- 30.989	.000		1		3.480E-14	3.480E- 14	3.480E- 14
	[FSC=4.00]	0 ^c			0				
2.00	Intercept	-4.972	4161.044	.000	1	.999			
	LENGTH	.000	.002	.055	1	.814	1.000	.996	1.004
	WIDTH	.021	.029	.528	1	.467	1.022	.964	1.082
	AGE	.014	.018	.606	1	.436	1.014	.978	1.052
	ADT	.000	.000	.001	1	.973	1.000	1.000	1.000
	EH	016	.030	.279	1	.598	.985	.929	1.043
	FSD	004	.026	.027	1	.869	.996	.947	1.047
	[DISTRICT=1.00]	18.093	2349.030	.000	1	.994	72037379.865	.000	.b
	[DISTRICT=4.00]	16.967	2349.029	.000	1	.994	23373245.447	.000	.b
	[DISTRICT=5.00]	19.462	2349.030	.000	1	.993	283228462.428	.000	. ^b
	[DISTRICT=6.00]	16.612	2349.029	.000	1	.994	16392243.251	.000	.b
	[DISTRICT=7.00]	17.134	2349.029	.000	1	.994	27625984.370	.000	.b
	[DISTRICT=9.00]	17.776	2349.029	.000	1	.994	52474867.233	.000	. ^b
	[DISTRICT=10.00]	17.041	2349.030	.000	1	.994	25171888.908	.000	. ^b
	[DISTRICT=11.00]	16.859	2349.029	.000	1	.994	20970639.872	.000	. ^b
	[DISTRICT=12.00]	0 ^c			0				-

[ABUT=1.00]	- 13.840	3434.581	.000	1	.997	9.762E-7	.000	. ^b
[ABUT=2.00]	075	.993	.006	1	.940	.927	.132	6.493
[ABUT=3.00]	0 ^c			0	-			
[APPT=1.00]	.898	.878	1.045	1	.307	2.453	.439	13.716
[APPT=2.00]	0 ^c			0				
[FSC=1.00]	- 13.082	3434.581	.000	1	.997	2.083E-6	.000	.b
[FSC=2.00]	- 14.185	3434.581	.000	1	.997	6.914E-7	.000	.b
[FSC=3.00]	- 13.552	3434.581	.000	1	.997	1.301E-6	.000	.b
[FSC=4.00]	0 ^c			0				

a. The reference category is: 3.00.

b. Floating point overflow occurred while computing this statistic. Its value is therefore set to system missing.

c. This parameter is set to zero because it is redundant.

Classification								
		Predicted						
Observed	1.00	2.00	3.00	Percent Correct				
1.00	11	1	2	78.6%				
2.00	2	22	12	61.1%				
3.00	3	8	26	70.3%				
Overall Percentage	18.4%	35.6%	46.0%	67.8%				

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Appendix G: Output of the Ordinal Logistic Regression for Sample Two

```
GET
FILE='C:\Users\jzh252\Desktop\Sample2.sav'.
DATASET NAME DataSet1 WINDOW=FRONT.
PLUM SEVERITY BY DISTRICT ABUT APPT FSC WITH LENGTH WIDTH AGE ADT EH
FSD
/CRITERIA=CIN(95) DELTA(0) LCONVERGE(0) MXITER(100) MXSTEP(5)
PCONVERGE(1.0E-6) SINGULAR(1.0E-8)
/LINK=LOGIT
/PRINT=FIT PARAMETER SUMMARY TPARALLEL.
```

PLUM - Ordinal Regression

Warnings

There are 1198 (66.7%) cells (i.e., dependent variable levels by observed combinations of predictor variable values) with zero frequencies. Unexpected singularities in the Fisher Information matrix are encountered. There may be a

quasi-complete separation in the data. Some parameter estimates will tend to infinity.

The PLUM procedure continues despite the above warning(s). Subsequent results shown

are based on the last iteration. Validity of the model fit is uncertain.

		N	Marginal
	-	IN	Percentage
SEVERITY	1.00	192	32.0%
	2.00	273	45.5%
	3.00	135	22.5%
DISTRICT	1.00	167	27.8%
	2.00	18	3.0%
	3.00	28	4.7%
	4.00	1	0.2%
	5.00	36	6.0%
	6.00	68	11.3%
	7.00	72	12.0%
	8.00	2	0.3%
	9.00	30	5.0%
	10.00	34	5.7%

Case Processing Summary

	11.00	45	7.5%
	12.00	99	16.5%
ABUT	1.00	151	25.2%
	2.00	72	12.0%
	3.00	377	62.8%
APPT	1.00	467	77.8%
	2.00	133	22.2%
FSC	1.00	35	5.8%
	2.00	170	28.3%
	3.00	171	28.5%
	4.00	224	37.3%
Valid		600	100.0%
Missing		0	
Total		600	

Model Fitting Information

	-2 Log			
Model	Likelihood	Chi-Square	df	Sig.
Intercept Only	1270.242			
Final	1009.932	260.310	23	.000

Link function: Logit.

Goodness-of-Fit

-	Chi-Square	df	Sig.
Pearson	1159.928	1173	.601
Deviance	1009.932	1173	1.000

Link function: Logit.

Pseudo R-Square

Cox and Snell	.352
Nagelkerke	.400
McFadden	.205

Link function: Logit.

	Parameter Estimates							
							95% Confide	ence Interval
			Std.				Lower	Upper
		Estimate	Error	Wald	df	Sig.	Bound	Bound
Threshold	[SEVERITY = 1.00]	1.533	.656	5.462	1	.019	.247	2.819
	[SEVERITY = 2.00]	4.380	.682	41.194	1	.000	3.043	5.718
Location	LENGTH	.000	.000	1.101	1	.294	.000	.001
	WIDTH	.006	.005	1.729	1	.189	003	.015
	AGE	.017	.005	13.194	1	.000	.008	.026
	ADT	1.910E- 5	6.424E- 6	8.841	1	.003	6.510E-6	3.169E-5
ĺ	EH	.005	.008	.307	1	.580	012	.021
	FSD	.002	.008	.085	1	.771	013	.017
ĺ	[DISTRICT=1.00]	-1.124	.269	17.487	1	.000	-1.651	597
	[DISTRICT=2.00]	2.992	.566	27.896	1	.000	1.881	4.102
	[DISTRICT=3.00]	258	.428	.363	1	.547	-1.097	.581
	[DISTRICT=4.00]	21.369	.000		1		21.369	21.369
	[DISTRICT=5.00]	1.870	.432	18.748	1	.000	1.023	2.716
	[DISTRICT=6.00]	.753	.336	5.029	1	.025	.095	1.411
	[DISTRICT=7.00]	2.234	.341	42.970	1	.000	1.566	2.902
	[DISTRICT=8.00]	2.170	1.492	2.115	1	.146	754	5.094
ĺ	[DISTRICT=9.00]	1.699	.424	16.091	1	.000	.869	2.529
ĺ	[DISTRICT=10.00]	-1.236	.417	8.790	1	.003	-2.054	419
ĺ	[DISTRICT=11.00]	.850	.369	5.302	1	.021	.126	1.573
ĺ	[DISTRICT=12.00]	0 ^a			0			
ĺ	[ABUT=1.00]	.570	.530	1.155	1	.282	469	1.609
	[ABUT=2.00]	.706	.554	1.626	1	.202	379	1.792
ĺ	[ABUT=3.00]	0 ^a			0			
ĺ	[APPT=1.00]	.529	.219	5.825	1	.016	.099	.958
ĺ	[APPT=2.00]	0 ^a			0			
ĺ	[FSC=1.00]	.316	.636	.247	1	.619	931	1.564
	[FSC=2.00]	.601	.558	1.158	1	.282	493	1.694
	[FSC=3.00]	.731	.541	1.826	1	.177	329	1.791

[FSC=4.00]	0 ^a		0		
	_	 <i>.</i>	_		-

Link function: Logit.

a. This parameter is set to zero because it is redundant.

Test	of Pa	rallel	Lines ^a
------	-------	--------	--------------------

	-2 Log			
Model	Likelihood	Chi-Square	df	Sig.
Null Hypothesis	1009.932			
General	978.310	31.621	23	.108

The null hypothesis states that the location parameters (slope coefficients) are

the same across response categories.

a. Link function: Logit.

Appendix H: Output of the Multinomial Logistic Regression for Sample Two

NOMREG SEVERITY (BASE=LAST ORDER=ASCENDING) BY DISTRICT ABUT APPT FSC WITH LENGTH WIDTH AGE ADT EH FSD /CRITERIA CIN(95) DELTA(0) MXITER(100) MXSTEP(5) CHKSEP(20) LCONVERGE(0) PCONVERGE(0.000001) SINGULAR(0.00000001) /MODEL /STEPWISE=PIN(.05) POUT(0.1) MINEFFECT(0) RULE(SINGLE) ENTRYMETHOD(LR) REMOVALMETHOD(LR) /INTERCEPT=INCLUDE /PRINT=CLASSTABLE FIT PARAMETER SUMMARY LRT CPS STEP MFI IC.

Nominal Regression

Warnings

There are 1198 (66.7%) cells (i.e., dependent variable levels by subpopulations) with zero frequencies.

Unexpected singularities in the Hessian matrix are encountered. This indicates that either

some predictor variables should be excluded or some categories should be merged.

The NOMREG procedure continues despite the above warning(s). Subsequent results

shown are based on the last iteration. Validity of the model fit is uncertain.

			Marginal
		Ν	Percentage
SEVERITY	1.00	192	32.0%
	2.00	273	45.5%
	3.00	135	22.5%
DISTRICT	1.00	167	27.8%
	2.00	18	3.0%
	3.00	28	4.7%
	4.00	1	0.2%
	5.00	36	6.0%
	6.00	68	11.3%
	7.00	72	12.0%
	8.00	2	0.3%
	9.00	30	5.0%
	10.00	34	5.7%

Case Processing Summary

	11.00	45	7.5%
	12.00	99	16.5%
ABUT	1.00	151	25.2%
	2.00	72	12.0%
	3.00	377	62.8%
APPT	1.00	467	77.8%
	2.00	133	22.2%
FSC	1.00	35	5.8%
	2.00	170	28.3%
	3.00	171	28.5%
	4.00	224	37.3%
Valid		600	100.0%
Missing		0	
Total		600	
Subpopula	ation	599 ^a	

a. The dependent variable has only one value

observed in 599 (100.0%) subpopulations.

Model Fitting Information

	Model Fitting Criteria			Likelih	ood Ratio Te	ests
			-2 Log			
Model	AIC	BIC	Likelihood	Chi-Square	df	Sig.
Intercept Only	1274.242	1283.035	1270.242			
Final	1080.788	1291.841	984.788	285.453	46	.000

Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	1128.538	1150	.669
Deviance	984.788	1150	1.000

Pseudo R-Square

Cox and Snell	.379
Nagelkerke	.430
McFadden	.225

_	Ν	lodel Fitting Criteri	Likelihood Ratio Tests			
			-2 Log			
	AIC of Reduced	BIC of Reduced	Likelihood of			
Effect	Model	Model	Reduced Model	Chi-Square	df	Sig.
Intercept	1080.788	1291.841	984.788ª	.000	0	
LENGTH	1079.497	1281.756	987.497	2.709	2	.258
WIDTH	1080.640	1282.899	988.640	3.852	2	.146
AGE	1091.009	1293.268	999.009	14.220	2	.001
ADT	1086.452	1288.711	994.452	9.664	2	.008
EH	1076.984	1279.243	984.984	.196	2	.907
FSD	1078.155	1280.414	986.155	1.367	2	.505
DISTRICT	1221.284	1335.604	1169.284	184.496	22	.000
ABUT	1076.706	1270.171	988.706	3.917	4	.417
APPT	1083.444	1285.703	991.444	6.655	2	.036
FSC	1071.878	1256.549	987.878	3.089	6	.798

Likelihood Ratio Tests

The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.

							95% Co Interval fo	nfidence or Exp(B)
		Std.					Lower	Upper
SEVERITY ^a	В	Error	Wald	df	Sig.	Exp(B)	Bound	Bound
1.00 Intercept	4.624	1.157	15.986	1	.000			
LENGTH	001	.001	.731	1	.393	.999	.998	1.001
WIDTH	015	.010	2.507	1	.113	.985	.966	1.004
AGE	029	.008	12.243	1	.000	.972	.956	.987
ADT	.000	.000	4.229	1	.040	1.000	1.000	1.000
EH	006	.015	.150	1	.699	.994	.966	1.023
FSD	003	.013	.056	1	.813	.997	.972	1.023
[DISTRICT=1.00]	2.278	.576	15.612	1	.000	9.754	3.151	30.188

Parameter Estimates

		-							
	[DISTRICT=2.00]	- 18.812	1870.596	.000	1	.992	6.761E-9	.000	. ^b
	[DISTRICT=3.00]	.452	.696	.422	1	.516	1.571	.402	6.146
	[DISTRICT=4.00]	-	000					8.827E-	8.827E-
		20.848	.000		1	•	8.827E-10	10	10
	[DISTRICT=5.00]	-3.749	1.130	11.006	1	.001	.024	.003	.216
	[DISTRICT=6.00]	980	.548	3.193	1	.074	.375	.128	1.099
	[DISTRICT=7.00]	-2.714	.562	23.316	1	.000	.066	.022	.199
	[DISTRICT=8.00]	- 17.614	4267.729	.000	1	.997	2.241E-8	.000	. ^b
	[DISTRICT=9.00]	-2.427	.745	10.619	1	.001	.088	.021	.380
	[DISTRICT=10.00]	16.495	1218.838	.000	1	.989	14581852.469	.000	.b
	[DISTRICT=11.00]	-1.356	.674	4.055	1	.044	.258	.069	.964
	[DISTRICT=12.00]	0 ^c			0				
	[ABUT=1.00]	749	.901	.690	1	.406	.473	.081	2.767
	[ABUT=2.00]	-1.246	.963	1.676	1	.196	.288	.044	1.898
	[ABUT=3.00]	0 ^c			0				
	[APPT=1.00]	977	.392	6.215	1	.013	.376	.175	.811
	[APPT=2.00]	0 ^c			0				
	[FSC=1.00]	188	1.088	.030	1	.863	.829	.098	6.988
	[FSC=2.00]	718	.950	.572	1	.450	.488	.076	3.137
	[FSC=3.00]	-1.026	.915	1.257	1	.262	.359	.060	2.154
	[FSC=4.00]	0 ^c			0				
2.00	Intercept	2.423	.913	7.050	1	.008			
	LENGTH	.000	.001	.052	1	.820	1.000	.999	1.001
	WIDTH	.002	.005	.094	1	.759	1.002	.991	1.012
	AGE	009	.007	2.041	1	.153	.991	.978	1.004
	ADT	.000	.000	5.707	1	.017	1.000	1.000	1.000
	EH	005	.012	.176	1	.675	.995	.972	1.019
	FSD	.007	.011	.423	1	.515	1.007	.986	1.029
	[DISTRICT=1.00]	1.549	.561	7.631	1	.006	4.708	1.568	14.134
	[DISTRICT=2.00]	-1.907	.606	9.893	1	.002	.149	.045	.487
	[DISTRICT=3.00]	.176	.656	.072	1	.788	1.193	.330	4.311
	[DISTRICT=4.00]	- 20.103	.000		1		1.859E-9	1.859E-9	1.859E-9
	[DISTRICT=5.00]	969	.504	3.696	1	.055	.380	.141	1.019

[DISTRICT=6.00]	140	.452	.096	1	.756	.869	.358	2.109
[DISTRICT=7.00]	-1.580	.423	13.946	1	.000	.206	.090	.472
[DISTRICT=8.00]	-1.072	1.529	.491	1	.483	.342	.017	6.860
[DISTRICT=9.00]	830	.504	2.709	1	.100	.436	.162	1.171
[DISTRICT=10.00]	15.721	1218.838	.000	1	.990	6720042.522	.000	.b
[DISTRICT=11.00]	.193	.501	.149	1	.700	1.213	.455	3.235
[DISTRICT=12.00]	0 ^c			0				
[ABUT=1.00]	319	.690	.214	1	.644	.727	.188	2.812
[ABUT=2.00]	082	.708	.014	1	.907	.921	.230	3.689
[ABUT=3.00]	0 ^c			0				
[APPT=1.00]	525	.343	2.344	1	.126	.592	.302	1.159
[APPT=2.00]	0 ^c			0				
[FSC=1.00]	383	.846	.205	1	.651	.682	.130	3.583
[FSC=2.00]	662	.722	.841	1	.359	.516	.125	2.123
[FSC=3.00]	846	.694	1.486	1	.223	.429	.110	1.672
[FSC=4.00]	0 ^c			0				

a. The reference category is: 3.00.

b. Floating point overflow occurred while computing this statistic. Its value is therefore set to system missing.

c. This parameter is set to zero because it is redundant.

	Predicted								
Observed	1.00	2.00	3.00	Percent Correct					
1.00	122	62	8	63.5%					
2.00	70	168	35	61.5%					
3.00	8	54	73	54.1%					
Overall Percentage	33.3%	47.3%	19.3%	60.5%					

Classification

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VITA

Jiwen Zhang was born to Bofu Zhang and Hengxia Wang in Linyi, Shandong, China. After graduating from No. 2 High School in Linyi, he attended Ludong University pursuing a Bachelor of Science degree in civil engineering, where he received several awards and assistantships to support his studies. During the process of pursuing a bachelor degree, he has gained a rich experience in bridge and road construction. After graduation from Ludong University, he continued to pursue a Master of Science in geotechnical engineering both in the Institute of Engineering Mechanics (IEM), China Earthquake Administration and Harbin Institute of Technology under the guidance of Professor Lingxin Zhang. IEM covered all expenses that he spent during master studies. He completed all necessary courses as required by this program in Harbin Institute of Technology, and then focused on structural seismic design and completed one project in the area of soil-structure interaction when he was in IEM. With the dream of learning the most advanced and most cutting-edge knowledge in construction engineering and project management, he entered into United States and continued to be a doctoral student as a research assistant in civil engineering at the University of Kentucky. He has completed one project related to bridge end settlement evaluation and prediction with his advisor Professor Tim Taylor. Two journal papers regrading this topic are going to be sent out for peer review. His research interests include logistic regression, structural seismic design, and deep excavation and support system.

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