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Bridge End Settlement Evaluation and Prediction

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Research Report
KTC-16-23/SPR14-486-1F

Bridge End Settlement Evaluation and Prediction

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16. Abstract

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 that rests 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; this assists designers in developing remediation plans during project development to minimize the lifecycle costs of bridge bump repairs. The study is based on historic bridge approach inspection data and maintenance history from a wide range of Kentucky roads and bridges. A macro method which considers a combination of maintenance times, maintenance measures, and observed settlement was used to classify the differential settlement scale as minimal, moderate, and severe. The scale corresponds to the approach performance status of 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 2 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 models are contained within a Microsoft Excel tool that allows users to select one or two models to predict the approach settlement level for a new bridge or for an existing bridge with different purposes.

The significance of this study lies in its identification of parameters that have the most influence on the settlement severity at bridge ends, and how those parameters interact in developing 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.

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INTRODUCTION

1.1 Background and Motivation

Differential settlement (also referred to approach settlement) between the bridge abutments and adjacent roadway pavement typically 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 state transportation agencies (STAs). 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) vehicle damage,
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) significant maintenance costs/works, and
i) delays and inconveniences caused by maintenance work.

Additionally, constant maintenance work, lane closures, and traffic control problems caused by structural issues can adversely impact the orderly flow of traffic and cause delay. In some cases, conducting maintenance on heavily trafficked roads is impossible without bringing traffic into a standstill. According to the Federal Highway Administration's (FHWA) "Priority, Market-Ready Technologies and Innovations" (FHWA-HRT-04-053), every year, the average driver experiences approximately 36 hours in delays due to traffic congestion prompted by road maintenance activities — or 5.7 billion person-hours.

In the United States, STAs devote significant financial and labor resources to address problems caused by differential settlement. Briaud et al. (1997) reported that 25 percent of the bridges nationwide (approximately 150,000) showed damage brought about by differential bridge approach settlement, and that over $100 million is spent on maintenance or repair every year. A survey (Laguros et al., 1990) of 61 transportation agencies concluded that almost 70% of the agencies considered differential settlement a significant issue. A more detailed survey (Hoppe, 1999) revealed that bridge approach settlement or bump problems were rated as a significant problem by 44% of STAs (Figure 1.1), including Kentucky. Furthermore, interviews with the local bridge engineers have suggested that differential settlement is a widespread problem in Kentucky. Dupont and Allen (2002) reported that nearly $1000 is spent per bridge per year to address approach settlement problems in Kentucky, which is slightly higher than the national average cost of $700 per bridge per year (Briaud et al., 1997).

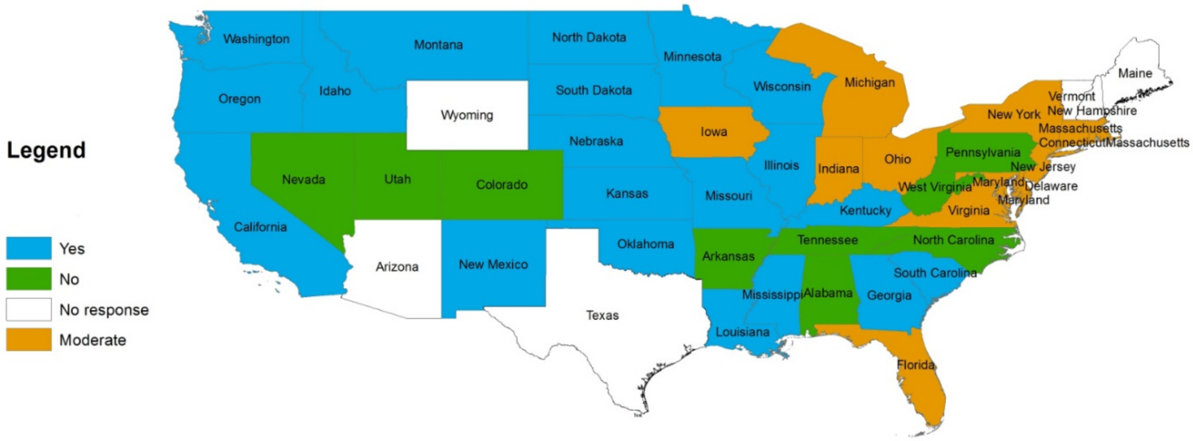


Figure 0.1 The significance of bridge approach settlement (Virginia DOT, 2003)

In 1999, the Virginia Department of Transportation (DOT) conducted a nationwide survey that asked STAs whether the settlement of approach slabs poses a significant problem. Table 1.1 summarizes the results of this survey. Approximately half of the states indicated that approach slab settlement is problematic.

Table 0.1 Is Approach slab settlement a significant problem? (Virginia DOT, 1999)

State	Yes	No	Moderate
AZ		X	
CA	X		
CT			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		
MO	X		
MT	X		
ND	X		
NE	X		
NH		X	
NJ			X
NM	X		
NY			X
OH			X
OK	X		
OR	X		
SC	X		
SD	X		
TX		X	
VT		X	
VA			X
WA	X		
WI	X		
WY		X	

Because of the serious consequences caused by differential settlement, numerous studies have been funded to determine why it occurs, to identify appropriate strategies to mitigate the problem, and to highlight advanced maintenance techniques that impose less of a burden on transportation agency maintenance budgets. The objective of this research is to develop a predictive model that can predict settlement and assist transportation agencies in determining remediation plans during project development based on given project characteristics. A key task of this research is to synthesize the key drivers of differential bridge end settlement and bump problems in Kentucky and to identify best practices for preventing them.

1.2 Definition of the *Bump* and Rating

Differential settlement occurs at the transition between a bridge and an adjoining roadway. Bridges and roadways are structures with very different supporting systems, which partially explains why differential settlement occurs. A bridge abutment is usually constructed on relatively firm soil, rock, or piles driven into a dense or stiff, deep, soil stratum which generates slight settlement. Settlement of the bridge abutment is negligible compared to roadway pavement, which is generally supported by a natural or filled soil subgrade.

The *bump* is a manifestation of the differential settlement in the area between the bridge and roadway interfaces (Anand J., 2009). Differential settlement typically occurs in the foundations of two cooperating structures that have been constructed under different design conditions. For roadways, this is located at the intersection of the roadway and bridge, which is normally indicated as approach pavement/slab. White et al. (2005) defined the term *bridge approach* as encompassing the area that stretches from the bridge structure/abutment to approximately 100 feet away from the abutment. This definition identifies the approach slab *and* the backfill and embankment areas beyond and under the approach slab as factors that significantly contribute to settlement around the bridge approach region.

Many researchers have studied bridge–roadway interfaces. Four methods have been summarized to define the approach settlement tolerance.

a) Bump is noticeable with approximately 0.5 inches of approach settlement (Wahls, 1990), and may lead to riding discomfort at approximately 2–2.5 inches (Stark et al., 1995). Walkinshaw (1978) suggested that differential settlement greater than 2.5 inches can result in a poor ride quality and calls for maintenance. Bozozuk (1978) concluded that differential settlement is tolerable up to 3.9 inches vertically and 2 inches horizontally. Hun Soo Ha et al (2002) developed a range to rate the bump scale (Table 1.2).

Table 0.2 Bump Scale Ratings (Hun Soo Ha, 2002)

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

b) Long et al. (1988) and Wahls (1990) recommended the use of a relative gradient, defined as a function of the length of the approach slab, of 1/125 as a threshold above which remedial action is necessary. Similarly, they identified a gradient less than 1/200 as providing satisfactory rider comfort. According to these thresholds, the required design length of an approach pavement/slab (L) can be estimated as: $L >= 200(sf - sa)$, where sf is the estimated total fill settlement at the end of the approach pavement/slab, and *sa* is the estimated settlement of the bridge abutment.

c) Several researchers have used the International Roughness Index (IRI). It is based on the accumulations of undulations under a given segment length and normally takes the form of mm/m or m/km. The index has been used to determine the magnitude of allowable bumps. The highest IRI value would be used to rate the performance of an approach. A rating system of bridge approaches using IRI was developed by Louisiana Transportation and Research Center (LTRC) (Das et al., 1999).

Table 0.3 Approach slab rating system developed by 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

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 thresholds to initiate maintenance procedures on transition zones.

1.3 Objectives and Tasks

KYTC and many other STAs, continually struggle with differential settlement at bridge ends. Bump issues can prove hazardous for motorists and motorcyclists. Additionally, bump issues are an ongoing source of maintenance spending, with an average of $1,000 spent per bridge per year in Kentucky (Dupont & Allen, 2002). Many have argued there is no resolution to this problem, and that some configurations of approach slabs, flooded backfills, or any other methods will produce differential settlement. The purpose of this research is not to study bump issues with the aim of developing design and construction techniques to minimize or eliminate the differential settlement at bridge ends. Rather, this study aims to identify best practices for minimizing or eliminating bump issues by analyzing other states' experience handling them. It develops a model to estimate the severity of differential settlement using specific project conditions derived from nearly 50 years of highway and bridge construction data in Kentucky. This model will assist KYTC in its efforts to monitor for differential settlement and make the necessary repairs when it occurs.

The main objective of this research is to develop a predictive model, focused at the macro level, to estimate the severity of differential settlement at bridge ends. It is critical to identify major project characteristics that contribute significantly to the development of an approach settlement, and to determine which characteristics could be defined quantitatively or qualitatively and used as inputs to build the model. This model will improve project stakeholders' monitoring programs and facilitate the development of more effective repair techniques. The research has the following sub-objectives:

a) Collect a body of design, construction, and maintenance data that describes a representative cross section of bridges and approaching roadways in Kentucky and the amount of bridge end settlement that has occurred at these bridges.
b) Identify recent developments in research associated with bridge ends, particularly those completed since KTC's last study in this area.
c) Analyze the collected data and conduct field interviews with district personnel to identify a subset of bridges that can be used to develop a predictive model for bridge end settlement during project planning and design.

1.4 Research Structure

The following tasks were used to accomplish this work:

a) Reviewed literature and publically available data resources on existing structures exhibiting differential bridge end settlement (geotechnical reports, project plans, United States Geological Survey, etc.) and literature related to predicting differential bridge end settlement.
b) Surveyed selected bridge approaches and qualitatively assessed causative factors. An online survey was administered to KYTC's 12 districts using Surveygizmo to identify bridges with excessive approach settlement, moderate approach settlement, or minimal approach settlement. Project characteristics and geotechnical conditions of these bridges were also requested. Approximately 35 district bridge engineers responded to this survey, and data on over 130 bridges with differential approach settlement were collected. These bridges were verified and used as the first sample to conduct regression analysis during subsequent studies. Next, field interviews with each district representatives were scheduled to verify the results of the survey and to acquire comprehensive understanding of differential settlement issues in each district. Advice on how to select bridges was obtained as well as advice on bridges to sample for the predictive model.
c) Developed a multivariate regression model for prediction of approach settlement.
d) Collected best practices for the treatment of bridge approach settlement. This phase reviewed literature on best practices for corrective methods in treating differential bridge end settlement. The KYTC corrective practices were documented through field interviews with local district bridge engineers. Lastly, based on previous studies, KYTC's methods to determine the timing for corrective measures were reviewed.
e) Developed a framework for application of settlement treatments that aligns with predicted settlement conditions. Based on the differential settlement prediction model, future or past bump problems can be predicted and then described using one of three categories — severe, moderate, or minimal. Model results were compared to actual bump conditions obtained through field interview

to validate its performance. Procedures and implementation measures for using the framework were developed.

1.5 Significance

Numerous studies have been conducted on differential bridge settlement. While some of them have leveraged statistical analysis, few have adhered to a systematic statistical method. Laguros and Zaman (1990) established a linear numeric model to explain the relationships between the approach settlement and causative factors by quantitatively defining these factors, but none of the categorical causing factors were included in this model. Previous studies on differential bridge settlement have a number of limitations, including neglecting all causative factors; overlooking specific techniques to eliminate or minimize the effects at specific locations/bridges; and developing conclusions that were not based on a robust statistical approach. This study addresses these problems by working at a macro level, drawing on a wide-ranging dataset of roads and bridges from around Kentucky to examine important causative factors. In doing so, it makes contributions that advance research knowledge and inform policy development. Researchers and engineers will benefit from having a rich understanding of the factors which contribute to the formation of approach settlement and the mitigation methods that are most effective under different circumstances. This work will give policymakers knowledge that will help them set guidelines on bridge design, construction, and maintenance work in order to minimize or eliminate approach settlement at bridge ends.

LITERATURE REVIEW

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 aims to provide a reference when a specific problem has emerged, after considering Kentucky construction policies and project characteristics.

1.6 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 contributed to differential settlement at bridge ends.

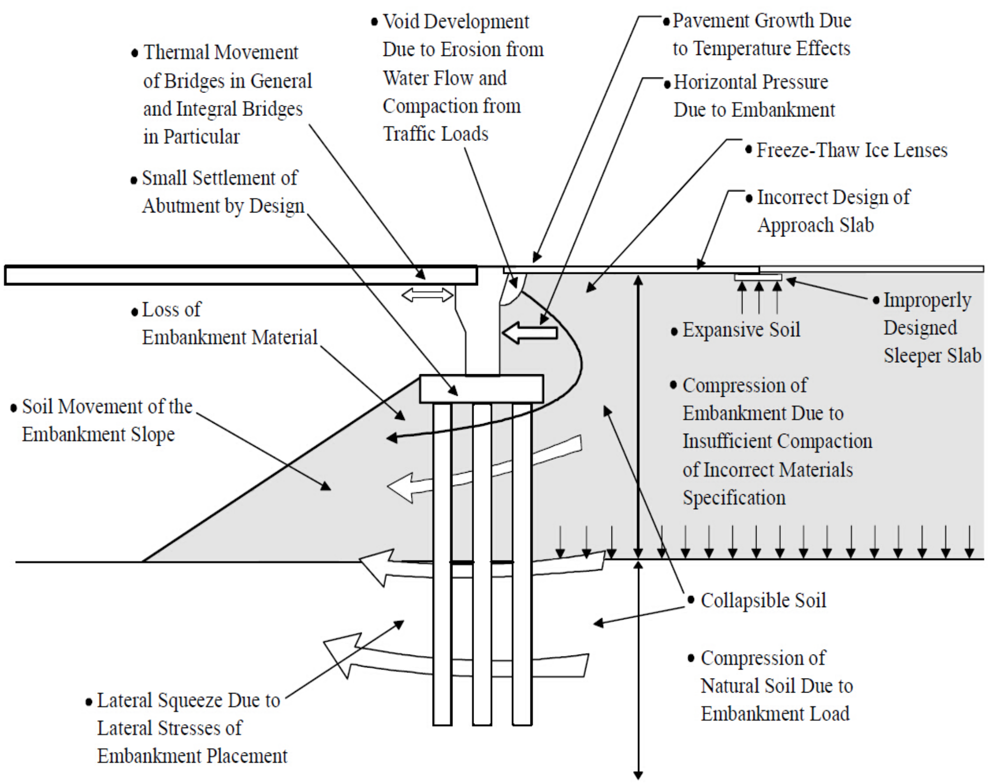


Figure 0.1 Schematic of various contributors leading to the existence of the bump at the bridge ends (Briaud et al., 1997)

Helwany (2007) classified different factors into five major categories. A summary of these factors is listed in Table 2.1.

Table 0.1 Summary of causes of bridge approach settlement (Helwany, 2007)

	Category	Causes
1	Poor Performance of Approach Pavement	Deformation in Flexible Pavement: Rutting, shoving or cracking
		Failures in Concrete Pavements: transverse cracking, joint faulting, corner breaks, or blowup
		Improper placement of roadway grades

2	Type of Bridge Abutments and Foundation Support	Lack of maintenance of expansion joints of Non-Integral Abutments causing temperature induced stresses on bridge abutment
		Ratcheting or cyclic movement of integral abutments resulting in lateral movement of abutment and increased lateral earth pressures
		Vertical movement of foundations (shallow vs. deep) in relationship to embankment stiffness
		Improper Abutment or Wingwall Design
3	Vertical and Lateral Deformation of Backfill	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 differences and drainage (i.e., frost heaving, thaw, collapsible soils, and swelling)
		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
4	Vertical and Lateral Deformation of Foundation Soil	Lateral squeeze of weak foundation soils due to increase vertical stresses (i.e., embankment weight)
		Consolidation settlement (primary & secondary) of silt, clay, and organic soils due to increased effective stress
		Slope stability failures due to soils with low shear strengths
5	Poor Drainage	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 fines migration
		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 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.

1.7 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 mitigation techniques may be required because of different site conditions.

Table 0.2 Mitigation methods of bridge approach settlement (Helwany, 2007)

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

Although approach settlement has been commonly recognized, given plenty of attention, and causes 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.

1.8 Application of Approach Slabs

One of the most popular measures to solve bump problems is the application of approach slabs. Approach slabs are reinforced concrete slabs supported at one end on the bridge abutment and at the other end on the embankment fill. They 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 & 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 no-use 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 of using 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 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. This study will investigate reasons that no clearly defined benefits from approach slabs were indicated by Kentucky. The primary benefits and drawbacks of using approach slabs are summarized in Table 2.4 and Table 2.5.

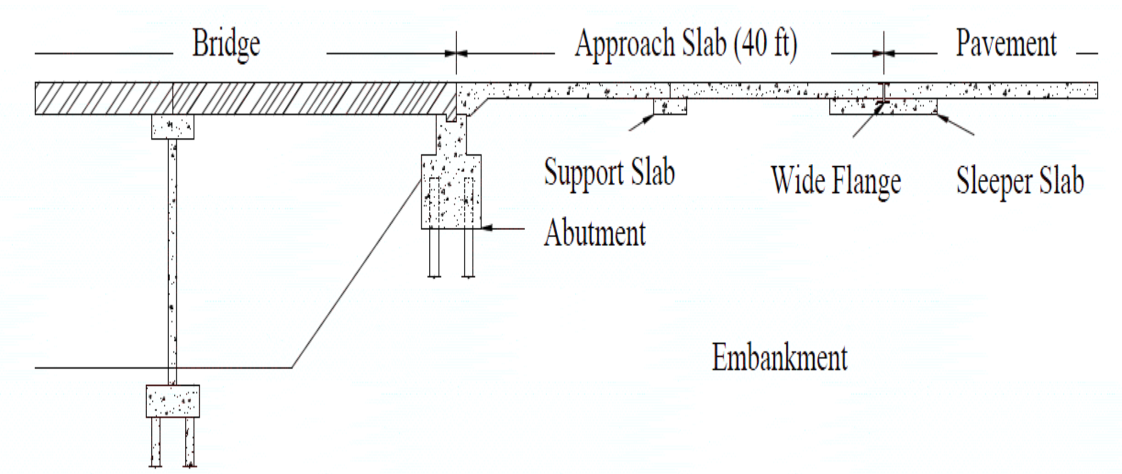


Figure 0.2 Schematic design of a typical approach slab (TxDOT, 2002)

Table 0.3 Current use of approach slabs (%) state interstate system, primary system, and secondary system (Hoppe, 1999)

State	Interstate System	Primary System	Secondary System
AL	100	100	20
AZ	100	100	80
CT	< 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
MD	<1	<2	0
MA	100	100	100
MN	90	69	8
MO	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
OH	100	95	75
OK	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

Table 0.4 Advantage of Using Approach Slabs (Hoppe, 1999)

State	Smooth Ride	Reduced Impact	Control Drainage	Uniform Settlement	Lower Maint. Cost	Seismic Stability	Minimum Deviation at Joints	None
AL	Δ	Δ						
AZ	Δ	Δ						
CA	Δ							
CT	Δ							
DE	Δ							
FL	Δ							
GA	Δ							
ID		Δ		Δ				
IL			Δ	Δ				
IN	Δ			Δ				
IO	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							
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				

Table 0.5 Disadvantage of using approach slabs (Hoppe, 1999)

State	Higher Initial Cost	Maint.	Erosion	Bending Stress at Backwall	Problems w/Staged Construction	Joints	Rough Surface	Increased Construction Time
CA	Δ							
DE	Δ	Δ	Δ					
GA		Δ	Δ					
IL	Δ							
IN	Δ							
IO	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							

The consensus is 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.

There is debate over 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) have an important impact on the performance of approach slabs, and a basic design of approach slab is recommended. Most researchers believe use of an approach slab 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 consensus has 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. The Kentucky Structural Design Manual (2005) stipulates a general design criteria of approach slabs and states where 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 was evaluated by statistical analysis between bridges with approach slabs and bridges without based on a large amount of bridges in Kentucky.

1.9 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, the 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.

DATA COLLECTION

1.10 Model Inputs Identification

As shown in the literature review, there are a variety of opinions on the causes of bridge approach settlements and consequently, the 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 causes as possible; no consensus has been reached on the role of each factor that affects bridge approach settlement. In other words, all contributing factors need to be collected and analyzed to see the weight of each variable on the predictive model, before selecting some of them to establish the optimum predictive model. A series of potential variables are identified and 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 & 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 have almost 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 approaches built with asphaltic concrete cement are termed as flexible. Evaluation of an approach slab's effect on mitigating differential settlement at bridge ends will be investigated in a separate section of this study.
3. Abutment type
   Abutments 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 abutments to settle more because it can be more difficult to bring large compaction equipment to compact the fill (Dupont & Allen, 2002). Perched abutments are usually constructed 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 & 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.

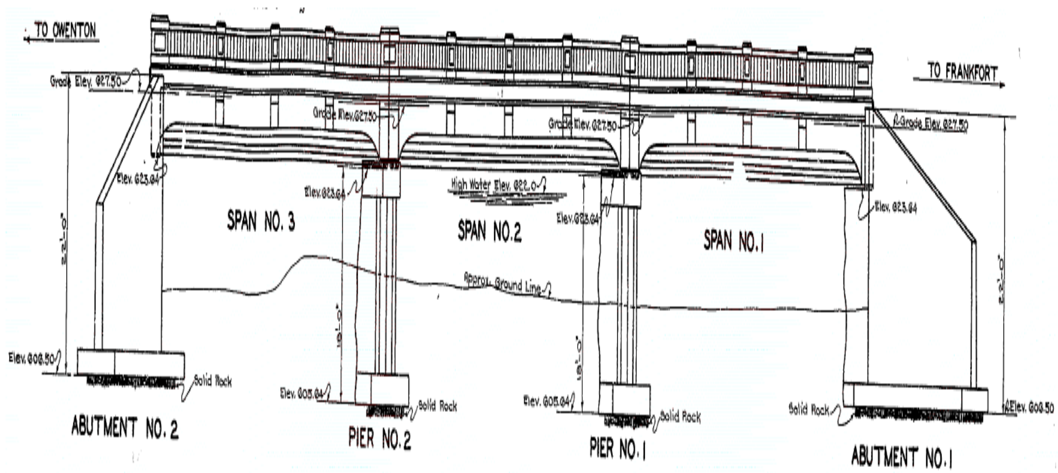


Figure 0.1 A typical full height closed or high abutment (bridge No. 094B00041N)

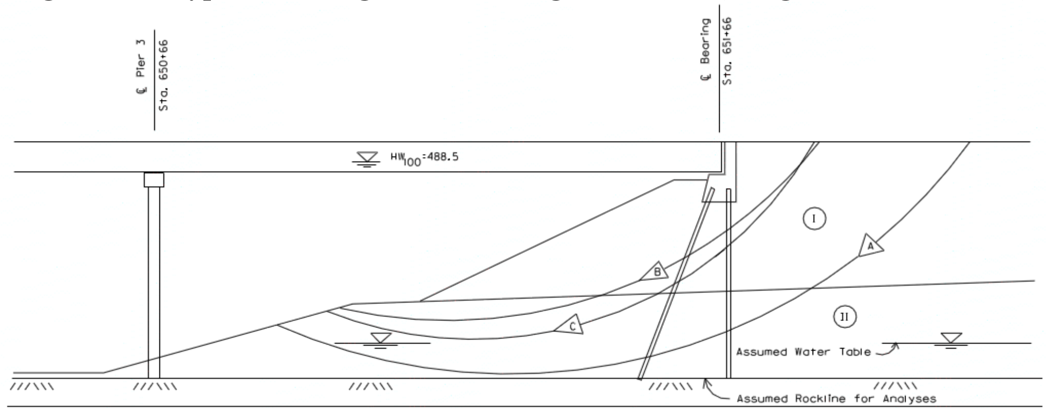


Figure 0.2 A typical perched abutment (bridge No. 056B00454R)

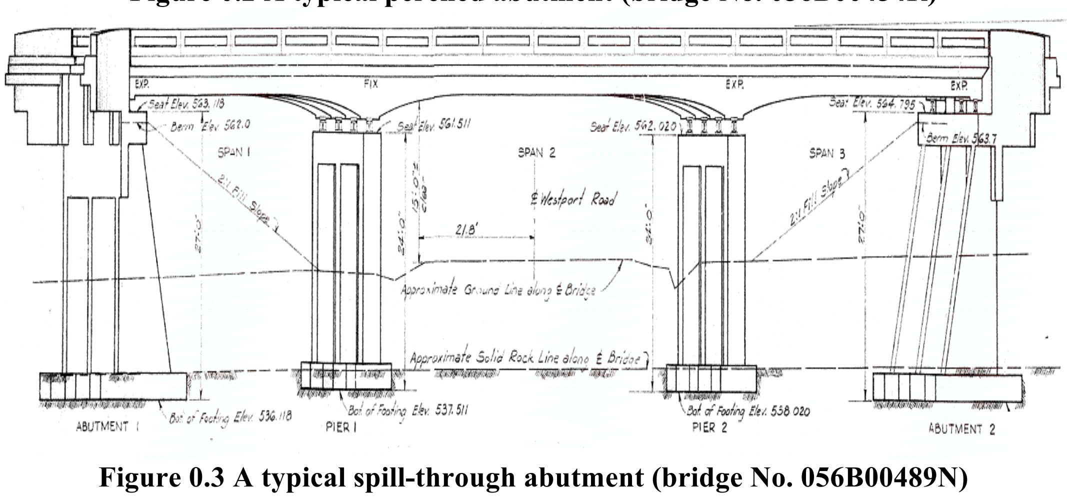


Figure 0.3 A typical spill-through abutment (bridge No. 056B00489N)

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 which covers 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 otherwise. Such a standardized fill composed of stabilized soil is inappropriate when 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 & 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 from the weight of the embankment itself (Dupont & 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 in 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 differs 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 that evaluates 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, considering drainage as a factor in logistic regressions is futile because almost every approach has adopted a drainage design as specified by KYTC. Another reasonable option that defines drainage as a numerical variable is to assign different grades by rating different designs of drainage. However, this information is not always available in KYTC's current data storage system.

1.11 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. For integral bridges, the superstructure is rigidly connected to the abutment in order to eliminate the use of bearing plates and to 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, integral bridges are more susceptible to temperature fluctuations as the abutment backfill is more affected by two 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 temperature flucuations as an important variable due to the following 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 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, among others. Kentucky is one of two states that believe 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 have no doweled or tied connection between approach slab and bridge 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.

Table 0.1 Connection between approach slab and bridge (Hoppe, 1999)

State	Non-integral Bridges		Integral Bridges		Integral Abutments Not Used
	Doweled or Tied	No Connection	Doweled or Tied	No Connection	
AL	×				×
AZ		×			
CA	×		×		
CT		×			
DE		×			×
FL	×				×
GA		×		×	
IA	×			×	
ID	×		×		
IL	×		×		
IN		×	×		
KS	×		×		
KY		×			
LA	×				
MA	×			×	
MD					×
ME		×	×		
MN		×	×		
MO	×				
MS		×			×
MT		×			
ND				×	
NJ		×			×
NH	×				
NV	×			×	
OH	×				
OK	×		×		
OR	×		×		
SC	×				
SD		×		×	
TN	×				
TX	×				×
VA		×	×		
VT	×				
WA	×		×		
WI		×			
WY	×		×		

1.12 Collection Method

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

- Once a bridge sample was 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 was identified explicitly from the site observation and verified from the design plan available at KYTC.
- Embankment height refers to elevation difference between the original ground level and the surface of the 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 (provided by Kentucky Geological Survey (KGS)). Foundation thickness underneath the embankment 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 within approximately 1-2 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 as an input but a discussion on how it may mitigate the bump problem is included in the current practice section of this report.

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 KYTC.

1.13 Model Output

Bridge approach settlement is the output of the anticipated model. The approach settlement here doesn’t refer to the real inches of settlement that the approach has experienced from the time it is open 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). A wise way of addressing the output from the macro angle is to classify the approach settlement severity as three levels: minimal, moderate, and severe.

One study conducted by Kentucky Transportation Center (KTC) (Dupont & Allen, 2002) indicated that the best practice to alleviate the bridge bump problem 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 approaches generally include local patching, mud/slab jacking, asphalt overlay, and replacement (Wahls, 1990; Briaud, 1997; Dupont & Allen, 2002; Hoyos, 2009). The term “local patching” refers to the maintenance performed at 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 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:

1. Examine 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 that catalogs maintenance history for a bridge even if some corrective actions were performed. However, there is an archive, named "Pontis", of most of bridges in Kentucky, which contains all inspection activities and suggested mitigation methods for the emerged problems, including suggestions for solving approach settlement. From the inspection history, the maintenance actions could be assumed to have been performed. 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."

1.14 Rating Output Levels

No uniform system has been established for rating bridge approaches due to differential settlement being a complicated mechanism. 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", or by 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 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 summarize the similarities and differences between micro and macro methods used to determine the differential settlement scale.

Table 0.2 Micro methods used to determine differential settlement scale

Rating	Description	Micro Method	
		Actual Settlement (Inch)	IRI (mm/m)
Very Good	No Bump	0	0~4
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 0.3 Macro method used to determine differential settlement scale

Rating	Description	Marco Method	
		Inspection History (Pontis): Characteristics	Survey: Characteristics
Good	No bump or minimal/slight bump	No settlement 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 to traffic.
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 periodic inspection reports.	Differential settlement can cause a minor impact and 1 to 3 maintenance fixes have been performed.
Poor	Severe bump	Settlement more than 3 inches was detected and problem lasts for a long time. Transitions have to be resurfaced or approach slabs need to be replaced.	Differential settlement can cause a major impact and maintenance work should be performed every couple of years.

1.15 Bridge Selection

1.15.1 Information from a Survey

An electronic questionnaire was created by "Surveygizmo" and distributed to managers of each transportation district. Then the link was sent 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 was 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. 35 bridge engineers participated in this survey, but only 18 engineers provided the completed and feasible information as requested. Data on 131 bridges with different settlement severity were obtained. The distribution of these bridges is shown in Table 3.4. No bridges from District 2 and District 8 were fed back. The bridge plans for only 87 bridges were identified in the current KYTC bridge archive because some bridges are too new or some information for these bridges is missing. These bridges comprise one sample for analysis. The relationship between approach settlement levels and predictors is discussed in the next chapter.

Table 0.4 Distribution of the bridges with different settlement levels from each transportation district for Sample One

District	Settlement Levels			Total No.
	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

1.15.2 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 the inspection history of most bridge approaches in Kentucky. Sample Two was created by randomly sampling and 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.

Every bridge in Sample Two had an equal opportunity to be selected. Therefore, a transportation district which has more bridges in “Pontis” has a higher probability that more bridges would be included in Sample Two. The method also guarantees that the sample includes bridges from every transportation district.

Table 0.5 Distribution of the bridges with different settlement levels from each transportation district for Sample Two

District	Settlement Levels			Total No.
	Minimal	Moderate	Severe	
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

1.16 Limitations of Data

Sampling is an important component of any piece of research because of the significant impact on the quality of results/findings. The samples used in this research were studied to obtain conclusions that represent the entire population. Hence, the accuracy of the conclusions was dependent upon the reliability of the data. This section 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. 131 bridges were collected for sample one, but only 87 had complete information that could be used for analysis. The research team contacted as many bridge maintenance engineers as possible to obtain a sufficient sample size. For logistic regression which is discussed in the next chapter, a model constructed from a small sample size may lead to unreliable conclusions.

Several survey responders provided the same bridges but noted different settlement levels. This phenomenon can be explained by two reasons. 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 — some maintenance engineers may have worked more than several decades in a district, where others may have been working for a particular district for a length of time that was much shorter than the age of the approach. If they judge the settlement level for a bridge based on their work experience, they may report different results. For example, if moderate and minimal settlement levels were given for the same bridge, moderate would be adopted. 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.

Generally, the bridges with the worst settlement situations may impress the responders most. In this case, Sample One may include more bridges with a severe rating than other settlement levels. The observed results verified this assumption. There were 60 bridges with severe settlement, of which 20 approaches were rated as minimal and 51 approaches as 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 "Pontis" only provides the inspection history for most of the bridges in Kentucky from the last ten years. The current situation of the settlement levels could be identified without giving earlier maintenance activities. 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.

The inspection history "Pontis" lists exact maintenance times and the types of maintenance activities undertaken for some bridges. While true settlement in inches was observed and 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, as shown in Table 3.3. For some bridges, "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.

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. The results will be expressed in terms of odds ratios: 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 will be implemented if the assumption that the slope coefficients in ordinal 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 variables is given in Table 4.1.

Table 0.1 Code sheet for the variables in samples

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

1.17 Approach Age

1.17.1 Sample One

This section discusses the approach age that influences 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.

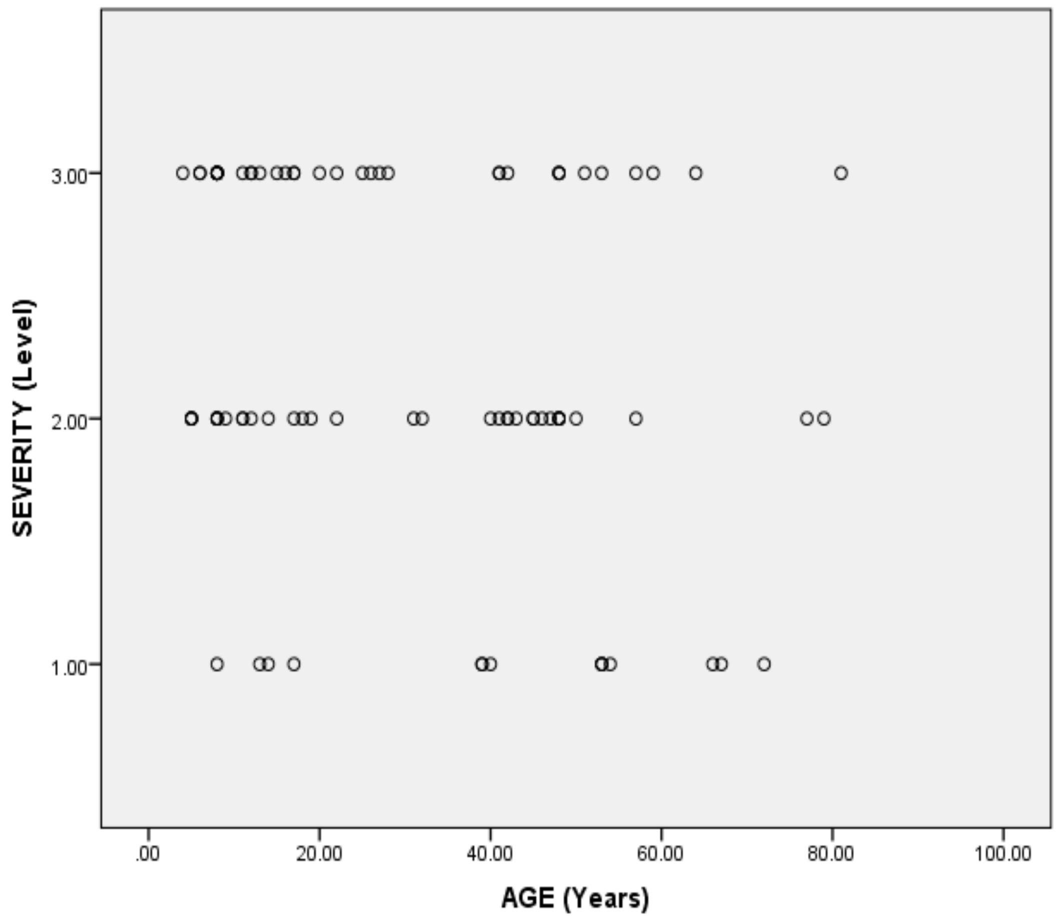


Figure 0.1 Sample One: Scatterplot of approach settlement levels by approach age

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 computing 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 0-30 years, 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 0-30 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 needs to be analyzed by logistic regression.

Table 0.2 Sample One: Frequency table of age group (AGEG) by SEVERITY

Age group (year)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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		

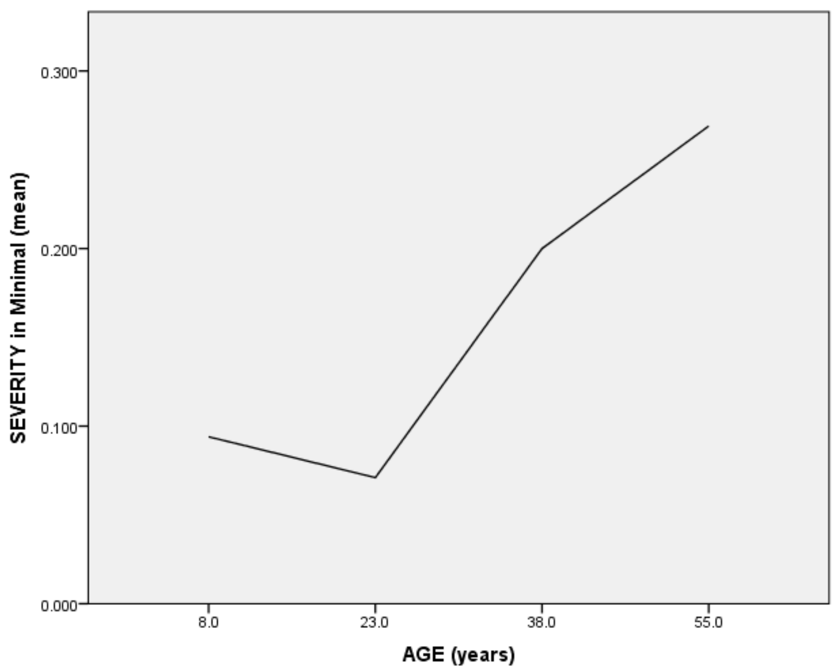


Figure 0.2 Sample One: Plot of the percentage of approaches with minimal SEVERITY in each age group

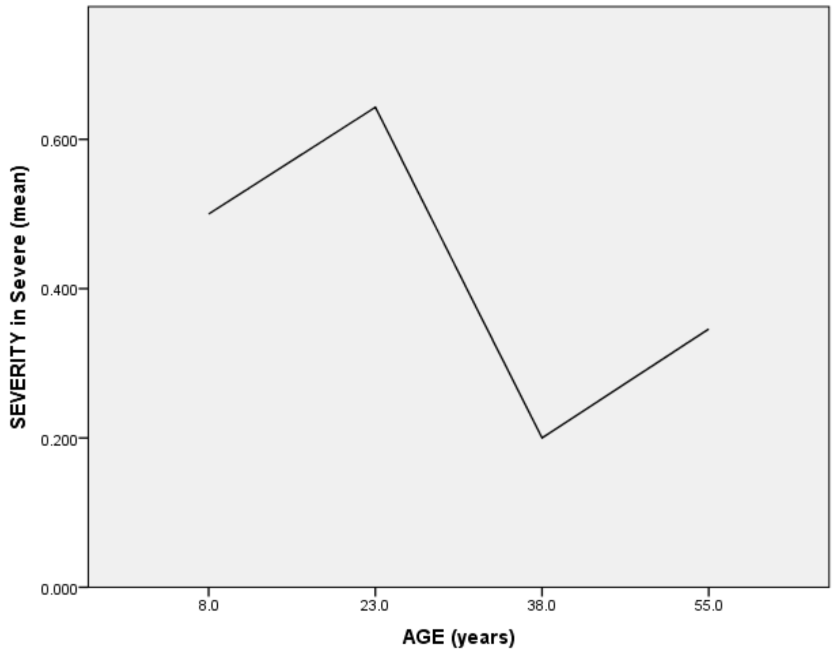


Figure 0.3 Sample One: Plot of the percentage of approaches with severe SEVERITY in each age group

Many statistical packages are able to conduct logistic regression analyses. Statistical Packages for the Social Sciences (SPSS) are 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 Tables 4.3, 4.4, and 4.5, each of which is discussed below.

Table 0.3 Sample One: Model fitting information of ordinal logistic regression between AGE and SEVERITY

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

- 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.
- 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 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 0.4 Sample One: Parameter estimates of ordinal logistic regression between AGE and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-2.349	.454	26.766	1	.000	-3.239	-1.459
	[SEVERITY = 2.00]	-.312	.363	.739	1	.390	-1.024	.400
Location	AGE	-.021	.010	4.661	1	.031	-.040	-.002

- 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 that the approaches' ages 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 classified as high SEVERITY, given that the approaches' ages 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.
- 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 that 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.

Table 0.5 Sample One: Test of parallel lines of ordinal logistic regression between AGE and SEVERITY

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

- 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:

$$Logit\frac{\pi_1}{1-\pi_1} = Logit\frac{\pi_1}{\pi_2+\pi_3} = -2.349 - 0.021AGE \tag{0.0}$$

$$Logit\frac{\pi_1+\pi_2}{1-(\pi_1+\pi_2)} = Logit\frac{\pi_1+\pi_2}{\pi_3} = -0.312 - 0.021AGE \tag{0.0}$$

Therefore,

$$\pi_1 = \frac{\exp(-2.349 - 0.021AGE)}{1+\exp(-2.349 - 0.021AGE)} \tag{0.0}$$

$$\pi_2 = \frac{\exp(-2.349 - 0.021AGE)}{1+\exp(-2.349 - 0.021AGE)} - \pi_1 \tag{0.0}$$

$$\pi_3 = 1 - \pi_1 - \pi_2 \tag{0.0}$$

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

1.17.2 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 with Sample One, no clear relationship could be revealed by this scatterplot.

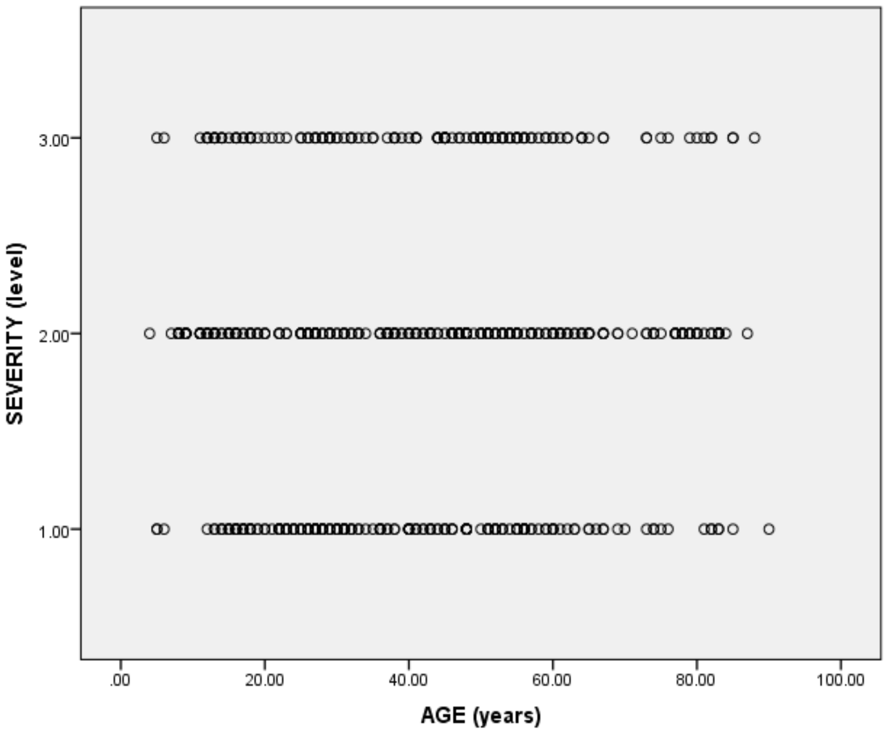


Figure 0.4 Sample Two: Scatterplot of approach settlement levels by approach age

Then the data in Sample Two was divided into four age groups to obtain the relationship between the percentage of SEVERITY with minimal settlement (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 Sample One.

Table 0.6 Sample Two: Frequency table of age group (AGEG) by SEVERITY

Age group (year)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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		

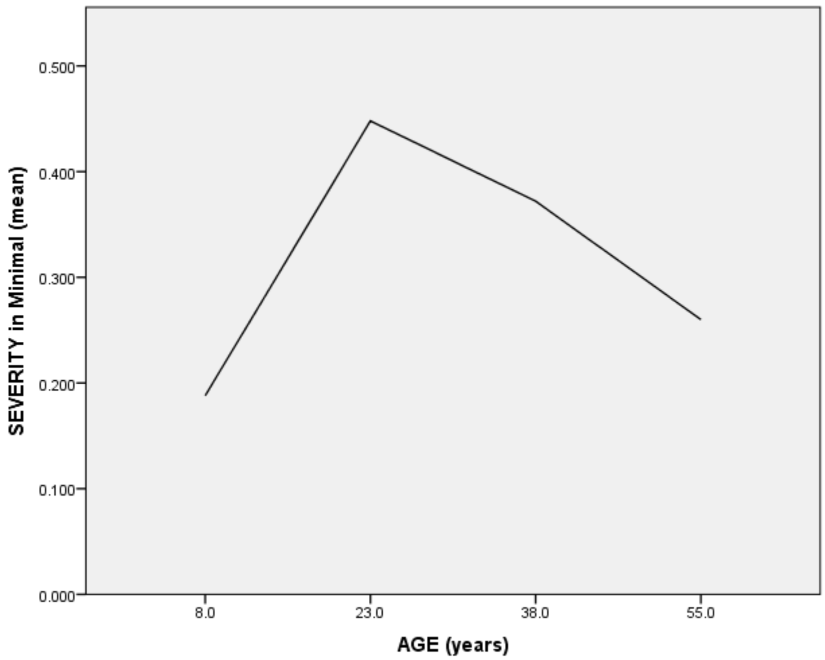


Figure 0.5 Sample One: Plot of the percentage of approaches with minimal SEVERITY in each age group

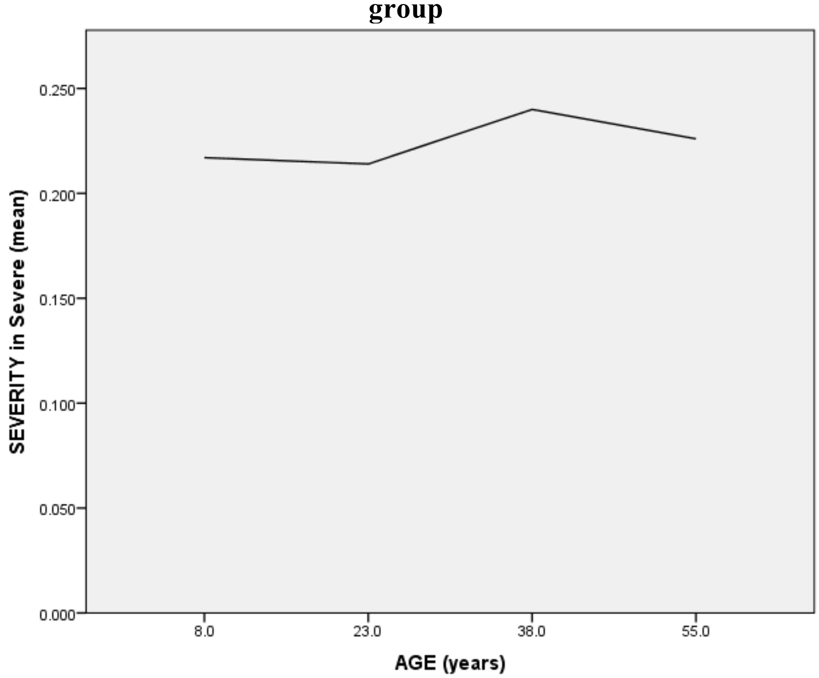


Figure 0.6 Sample Two: Plot of the percentage of approaches with severe SEVERITY in each age group

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 when 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 0.7 Sample Two: Model fitting information of ordinal logistic regression between AGE and SEVERITY

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

Note: Link function: Logit

Table 0.8 Sample Two: Parameter estimates of ordinal logistic regression between AGE and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-.524	.176	8.910	1	.003	-.868	-.180
	[SEVERITY = 2.00]	1.473	.186	62.806	1	.000	1.108	1.837
Location	AGE	.006	.004	2.221	1	.136	-.002	.013

Table 0.9 Sample Two: Test of parallel lines of ordinal logistic regression between AGE and SEVERITY

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

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

1.17.3 Conclusions

The ordinal regression is applicable when exploring the relationship between the settlement severity and the approach age. The result of Sample One is not exactly the same as 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 Sample One is different with Sample Two. This divergence could be explained by several events: (1) two samples were based on different evaluation criterions of settlement severity with different sample size, (2) the outcome of Sample One was determined by local bridge engineers when work experience varied from person to person, and (3) the predictor variable AGE was classified as a 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 may have led to an unstable model.

Most types of logistic regression, using maximum likelihood estimates, require sufficient sample size. How big is big is a topic of 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 the model of Sample One, while 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.

1.18 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 the literature. The variables LENGTH and WIDTH were treated the same as AGE. A descriptive relationship was depicted first, and then the changing tendency of proportion (mean) of approaches with minimal or severe settlement was illustrated. Finally, statistical package SPSS was used to discover any functional relationship between the bridge length (width) and the settlement severity.

1.18.1 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, as shown in Table 4.10. It 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 of minimal settlement while the approaches with bridge length between 200 and 300 feet have the lowest proportion of 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 with severe settlement falls in the range between 0 and 100 feet, while the lowest proportion of approaches with severe settlement lies in the range between 100 and 200 feet.

Table 0.10 Sample One: Frequency table of length group (LENGTHG) by SEVERITY

Length group (feet)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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		

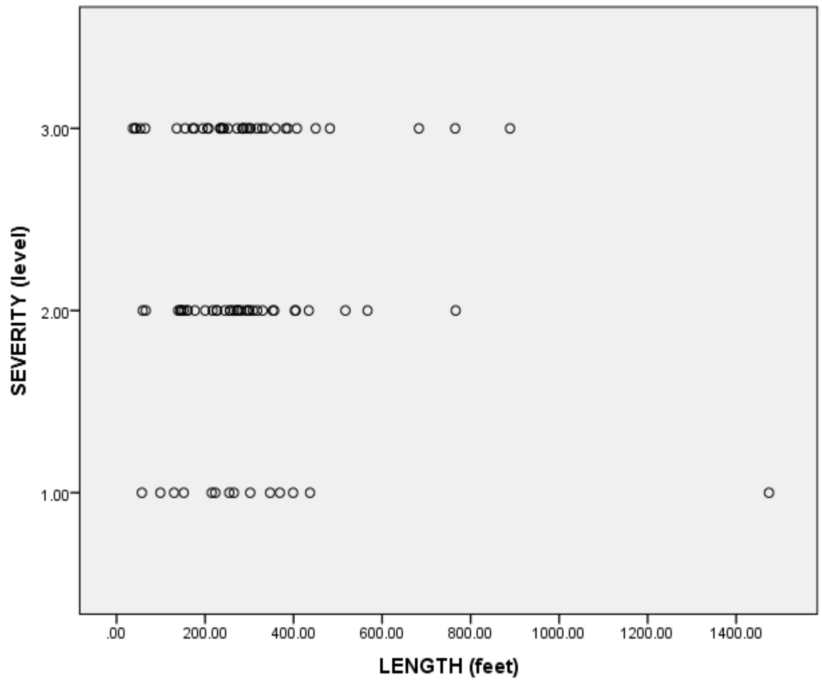


Figure 0.7 Sample One: Scatterplot of approach settlement levels by bridge length

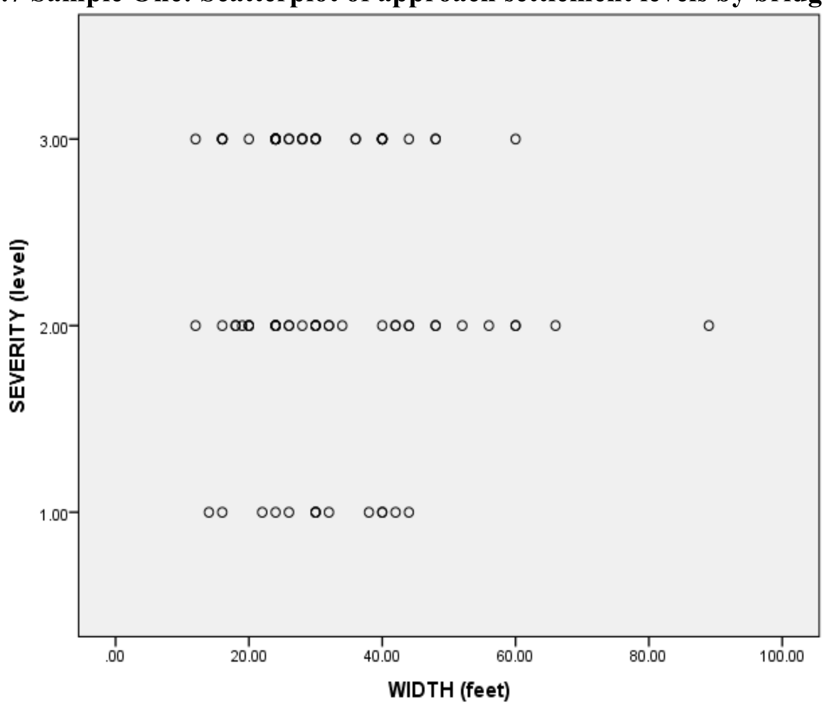


Figure 0.8 Sample One: Scatterplot of approach settlement levels by bridge width

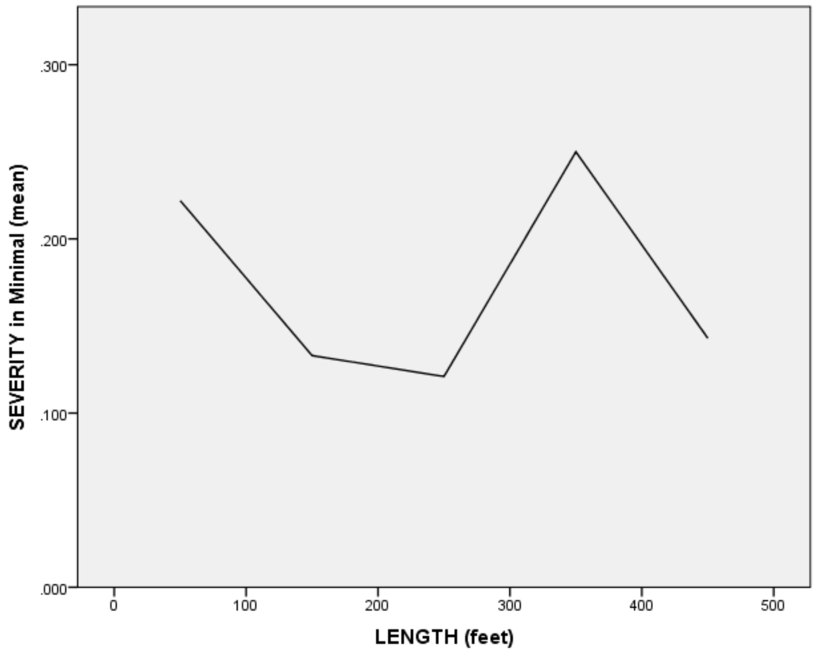


Figure 0.9 Sample One: Plot of the percentage of approaches with minimal SEVERITY in each length group

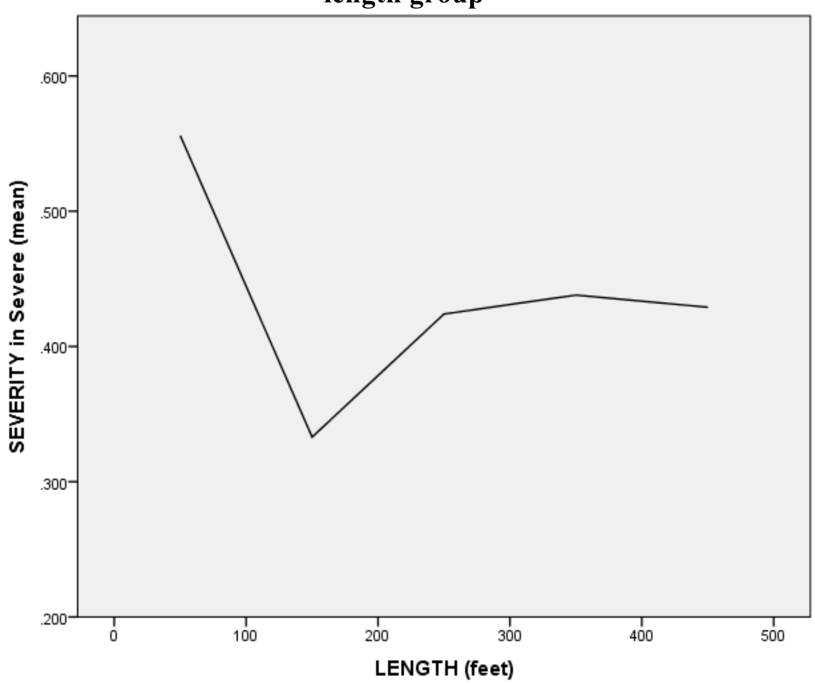


Figure 0.10 Sample One: Plot of the percentage of approaches with severe SEVERITY in each length group

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 decreases as width increases after 40 feet.

Table 0.11 Sample One: Frequency table of width group (WIDTHG) by SEVERITY

Width Group (feet)	Severity			Total	Mean	
	Minimal	Moderate	Severe		Minimal	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		

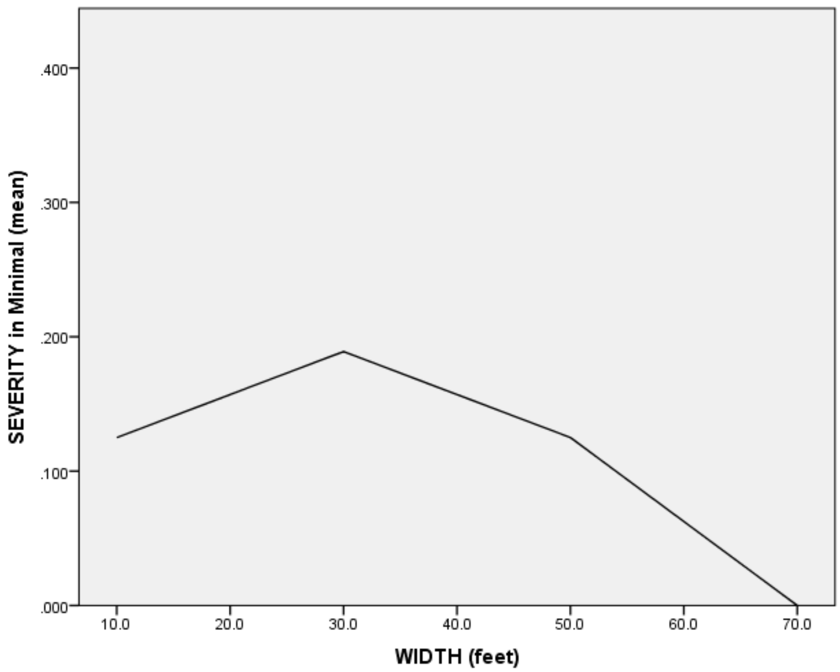


Figure 0.11 Sample One: Plot of the percentage of approaches with minimal SEVERITY in each width group

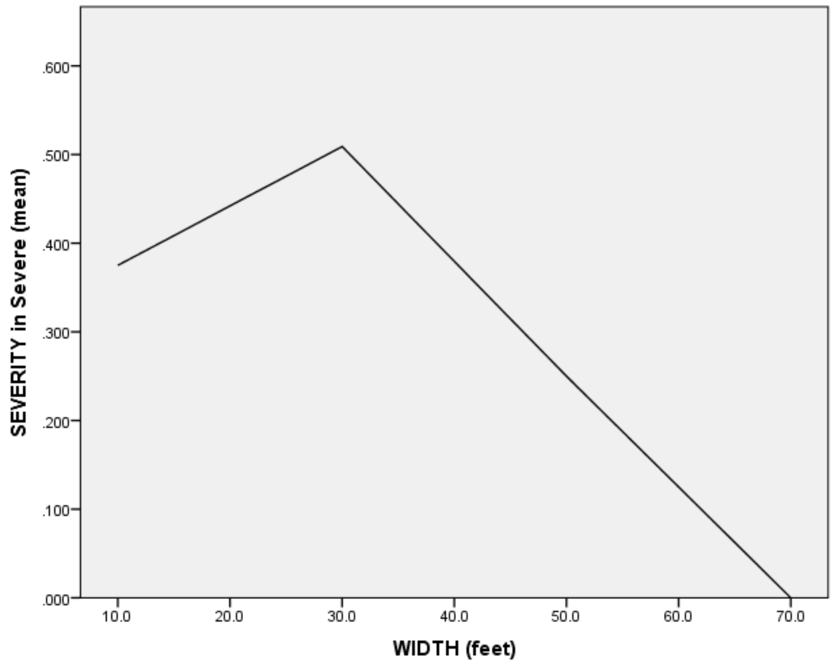


Figure 0.12 Sample One: Plot of the percentage of approaches with severe SEVERITY in each width group

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 through 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 and SEVERITY relationship is not statistically significant, 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 of 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 and thus cannot be rejected. Because these two models cannot reflect the relationships in this section very well, the expressions of these two models in equations are not given here.

Table 0.12 Sample One: Model fitting information of ordinal logistic regression between LENGTH and SEVERITY

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

Table 0.13 Sample One: Parameter estimates of ordinal logistic regression between LENGTH and SEVERITY

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

Table 0.14 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 0.15 Sample One: Model fitting information of ordinal logistic regression between WIDTH and SEVERITY

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

Table 0.16 Sample One: Parameter estimates of ordinal logistic regression between WIDTH and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-2.021	.579	12.199	1	.000	-3.155	-.877
	[SEVERITY = 2.00]	-.057	.517	.012	1	.913	-1.091	.976
Location	WIDTH	-.011	.015	.534	1	.465	-.041	0.019

Table 0.17 Sample One: Test of parallel lines of ordinal logistic regression between WIDTH and SEVERITY

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

1.18.2 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 for Sample Two shows a similar changing trend with Sample One: the proportion of minimal severity increases as the length increases at first, then decreases as the length increases in the middle range, and then increases as the length increases after 400 feet. 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 is less than 20 feet, and then decreases if the bridge width continues to increase. This changing trend is also similar to what occurs with Sample One.

Table 0.18 Sample Two: Frequency table of length group (LENGTHG) by SEVERITY

Length group (feet)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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		

Table 0.19 Sample Two: Frequency table of width group (WIDTHG) by SEVERITY

Width Group (feet)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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		

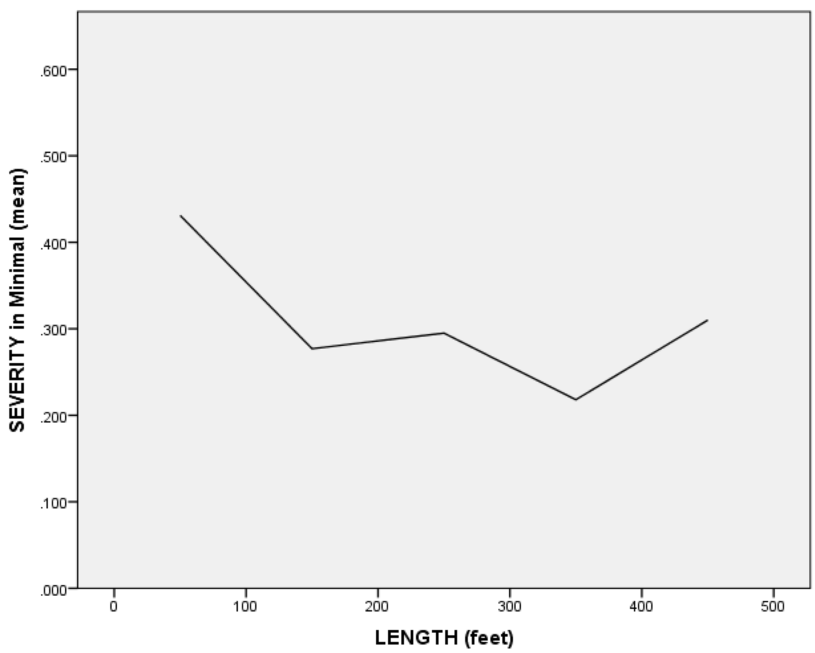


Figure 0.13 Sample Two: Plot of the percentage of approaches with minimal SEVERITY in each length group

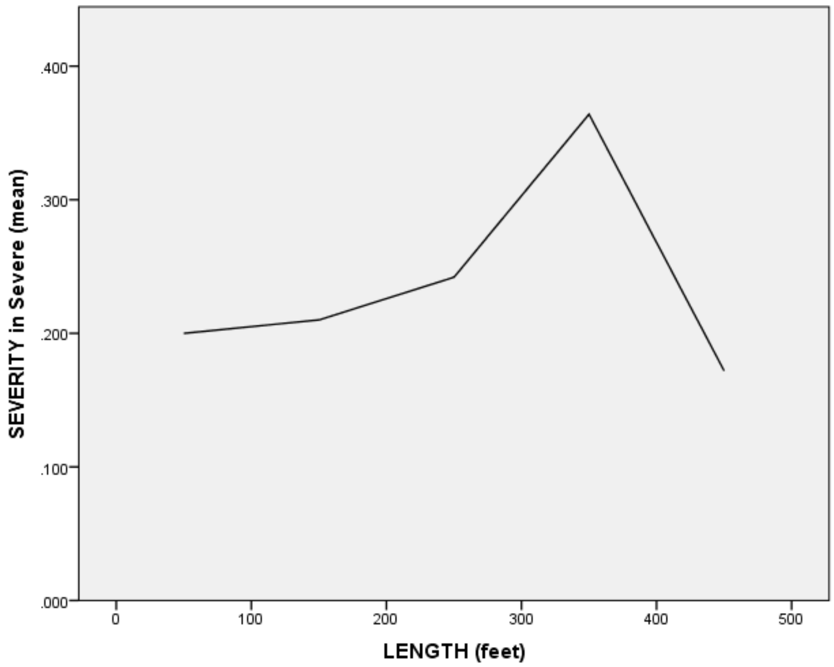


Figure 0.14 Sample Two: Plot of the percentage of approaches with severe SEVERITY in each length group

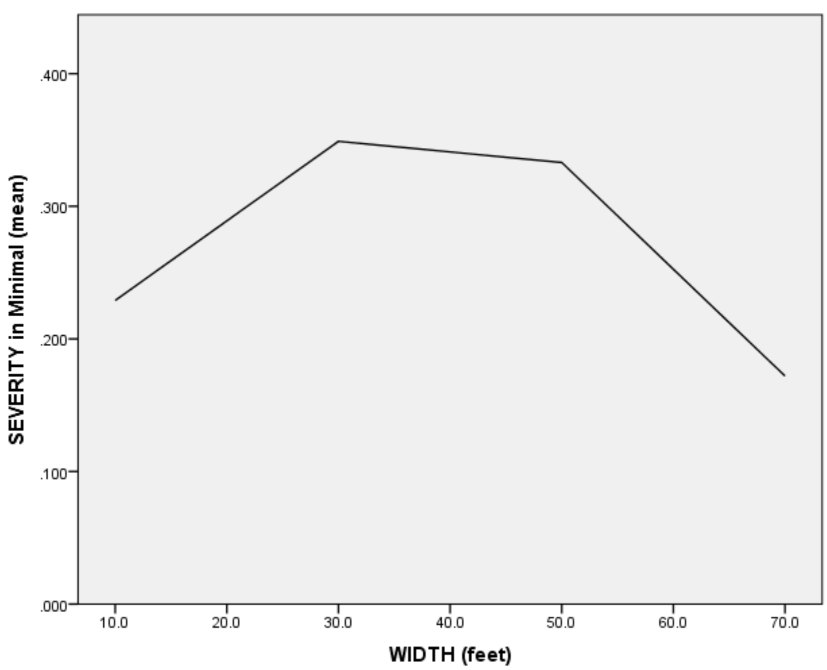


Figure 0.15 Sample Two: Plot of the percentage of approaches with minimal SEVERITY in each width group

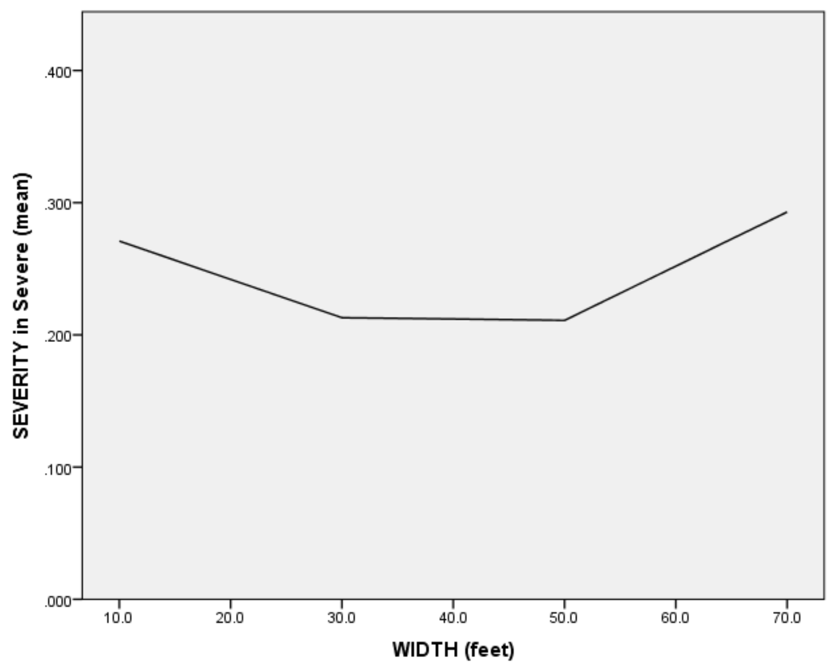


Figure 0.16 Sample Two: Plot of the percentage of approaches with severe SEVERITY in each width group

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

$$Logit\frac{\pi_1}{1-\pi_1} = Logit\frac{\pi_1}{\pi_2+\pi_3} = -0.355 + 0.011WIDTH \qquad (0.0)$$

$$Logit\frac{\pi_1+\pi_2}{1-(\pi_1+\pi_2)} = Logit\frac{\pi_1+\pi_2}{\pi_3} = 1.661 + 0.011WIDTH \qquad (0.0)$$

The probability relationship between different settlement levels are shown in equations 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 0.20 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 0.21 Sample Two: Parameter estimates of ordinal logistic regression between LENGTH and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-.660	.111	35.107	1	.000	-.878	-.442
	[SEVERITY = 2.00]	1.336	.123	118.743	1	.000	1.096	1.577
Location	LENGTH	.000	.000	1.760	1	.185	.000	.001

Table 0.22 Sample Two: Test of parallel lines of ordinal logistic 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 0.23 Sample Two: Model fitting information of ordinal logistic regression between WIDTH and SEVERITY

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

Table 0.24 Sample Two: Parameter estimates of ordinal logistic regression between WIDTH and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-.355	.157	5.135	1	.023	-.662	-.048
	[SEVERITY = 2.00]	1.661	.172	93.352	1	.000	1.324	1.998
Location	WIDTH	.011	.004	9.025	1	.003	.004	.018

Table 0.25 Sample Two: Test of parallel lines of ordinal logistic regression between WIDTH and SEVERITY

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

1.18.3 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 slightly high 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 occurs (given all of the other variables in the model are held constant). This conclusion should be compared to the comprehensive model which is illustrated in the last section of this chapter.

1.19 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 & 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 have almost no effect on the performance of bridge approaches. The relationship between ADT and Severity would be identified in this section.

1.19.1 Sample One

It is not appropriate to process ADT as AGE because the variability in ADT ranges in magnitude from tens to hundreds of thousands. Therefore, no scatterplots or proportions for the relationship between tendency of approaches and ADT were described. The output from SPSS was used to inference the relationship between ADT and SEVERITY.

Table 0.26 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

Table 0.27 Sample One: Parameter estimates of ordinal logistic regression between ADT and SEVERITY

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

Table 0.28 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 of 0.452 concluded that this model does not differ from a null model. The regression coefficient for ADT is 0.504, which indicates ADT is not significantly related to 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 of 0.05 is specified. A less restrictive model (multinomial logistic regression) was used to verify the output from ordinal regression.

Table 0.29 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 0.30 Sample One: Parameter estimates of multinomial logistic regression between ADT and SEVERITY

SEVERITY		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower Bound	Upper 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 equation 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 case as the referent group and therefore estimated a model for the relationship between Minimal and Severe and a model for the relationship between Moderate and 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 compares to the risk of the outcome falling in the referent group— this risk 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 comparison group relative to 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 value of the logit equation for SEVERITY relative to the referent group is expected to change by its respective parameter estimate (which is in log-odds units) if 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 (if the other variables in the model are held constant), the multinomial log-odds of becoming Minimal 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 (if 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 that considers all other predictors.

1.19.2 Sample Two

An ordinal regression was carried out at first and the output is shown in Tables 4.31 through 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 is violated, shown by slope coefficients in the model being the same across response categories. 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 0.31 Sample Two: Model fitting information of ordinal logistic regression between ADT and SEVERITY

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

Table 0.32 Sample Two: Parameter estimates of ordinal logistic regression between ADT and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper 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 0.33 Sample Two: Test of parallel lines of ordinal logistic regression between ADT and SEVERITY

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

Table 0.34 Sample Two: Model fitting information of multinomial logistic regression between ADT and SEVERITY

	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 0.35 Sample Two: Parameter estimates of multinomial logistic regression between ADT and SEVERITY

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

Note: The reference category is 3.

Table 0.36 Sample Two: Classification table of multinomial logistic regression between ADT and SEVERITY

Observed	Predicted			
	1.00	2.00	3.00	Percent 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.

1.19.3 Conclusions

The test of parallel lines of ordinal logistic regression between ADT and SEVERITY has shown that the null regression is violated for both Sample One and Sample Two, shown by the slope coefficients in the model being the same across response categories. This 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 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 settlement level may occur as ADT grows larger.

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

1.20 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 focused on the bump problems at bridge ends that could be minimized when an approach slab was 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 at a length that spans the problematic area or built stronger to prevent cracking.

Placing good pavement joints leading into the approach slab is another successful approach. 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.

Since fewer approach slabs are used in Kentucky, this section intends to verify whether approach slabs are useful or not for mitigating bump problems. The results were based on the performance of approach slabs that have been constructed in Kentucky.

1.20.1 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 contained inside. 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 the 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 the 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. The bridges with flexible approaches have a higher proportion of moderate settlement.

Table 0.37 Sample One: Frequency table of approach type (APPT) by SEVERITY

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

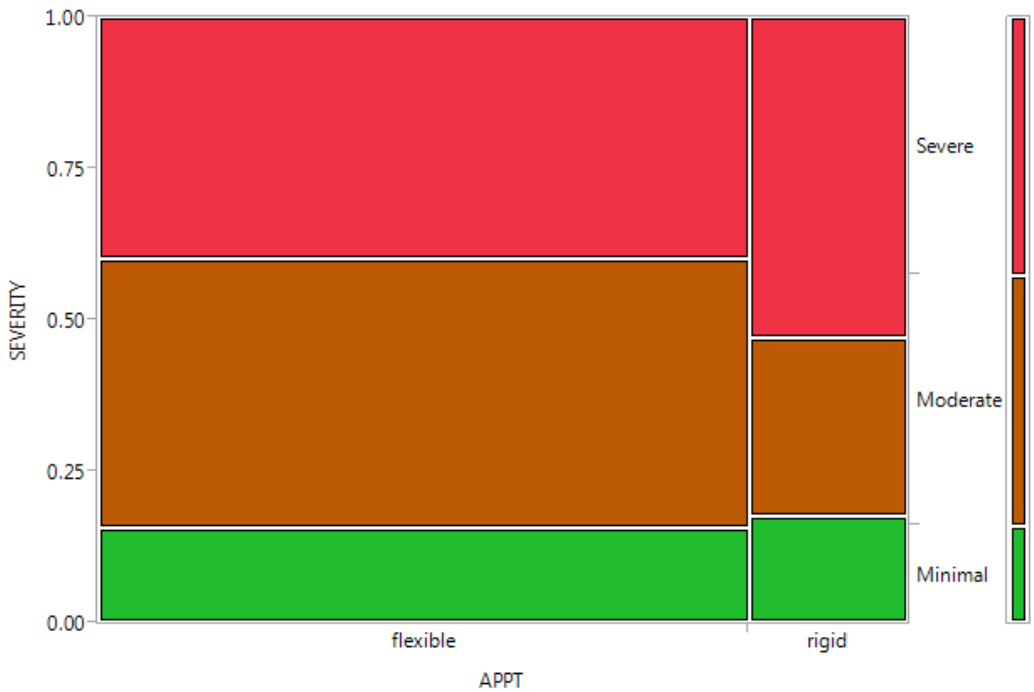


Figure 0.17 Sample One: Distribution of settlement levels across approach type

An attempt was made to create a model that describes the relationship between APPT and SEVERITY, using SPSS. The output is shown in Tables 4.38 through 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 0.38 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

Table 0.39 Sample One: Parameter estimates of ordinal logistic regression between APPT and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-1.957	.520	14.190	1	.000	-2.976	-.939
	[SEVERITY = 2.00]	.003	.468	.000	1	.995	-.913	.919
Location	[APPT=.00]	-.367	.516	.505	1	.477	-1.378	.645
	[APPT=1.00]	0[a]	.	.	0	.	.	.

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

Table 0.40 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 the 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, the Chi-square test is not appropriate for Sample One.

1.20.2 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.

Table 0.41 Sample Two: Frequency table of approach type (APPT) by SEVERITY

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

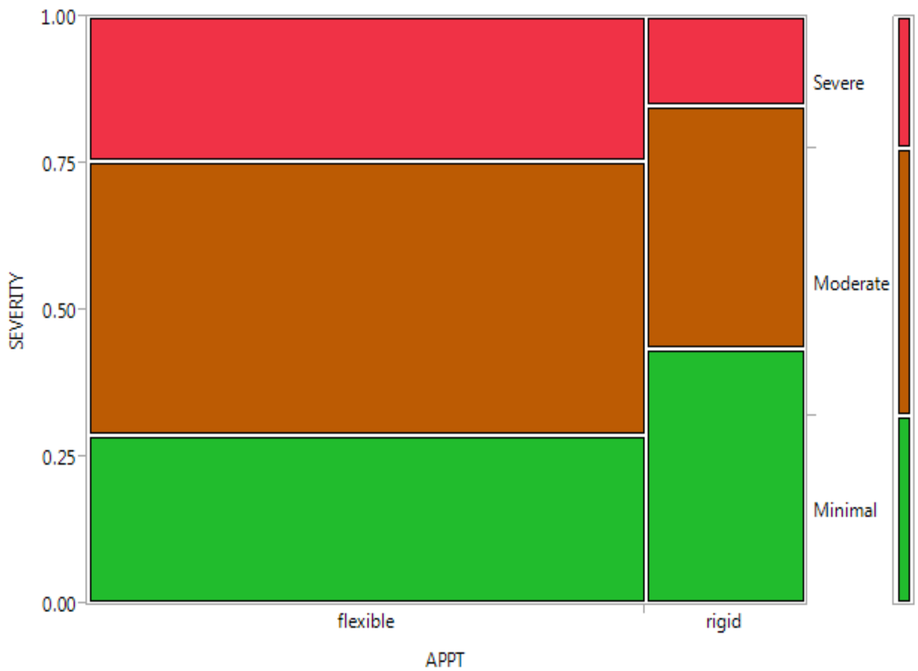


Figure 0.18 Sample Two: Distribution of settlement levels across approach type

Table 0.42 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 0.43 Sample Two: Parameter estimates of ordinal logistic regression between APPT and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-.265	.166	2.558	1	.110	-.591	.060
	[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	.	.	.

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

Table 0.44 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 p-value 0.001. The table of parameter estimates shows 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 if 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, the Chi-square test is performed. 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 when predicting 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 knowing the approach type is helpful when predicting 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 the Chi-square test is used to examine whether these two variables are independent.
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:

$$DF = (r - 1) * (c - 1) \tag{0.0}$$

   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.

$$E_{r,c} = (n_r * n_c)/n \tag{0.0}$$

   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.

Table 0.45 Sample Two: APPT VS. SEVERITY cross tabulation

			SEVERITY			Total
			Minimal	Moderate	Severe	
APPT	Flexible	Count	134	218	115	467
		Expected Count	149.4	212.5	105.1	467.0
	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

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

$$X^2 = \sum \left[(O_{r,c} - E_{r.c})^2 / E_{r.c} \right] \quad (0.0)$$

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. The Chi-square Distribution Calculator found $P(x^2 > 12.01) = 0.002$.

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 the Chi-square test using SPSS, which is the same with the result calculated by using the Chi-square Distribution Calculator.

Table 0.46 Sample Two: Chi-square test for APPT VS. SEVERITY

	Value	df	Asymp. Sig. (2-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		

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 concludes 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 levels minimal, moderate, and severe, respectively.

Table 0.47 Sample Two: Rating system to quantify approach effectiveness

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

An effective ratio (ER) is defined as:

$$ER = \frac{Total\ grade\ of\ rigid\ approaches\ in\ different\ settlement\ level \Big/ count\ of\ rigid\ approaches}{Total\ grade\ of\ flexible\ approaches\ in\ different\ settlement\ level \Big/ count\ of\ flexible\ approaches}$$

ER

$$= \frac{Total\ grade\ of\ rigid\ approaches\ in\ different\ settlement\ level \Big/ Count\ of\ rigid\ approa}{Total\ grade\ of\ flexible\ approaches\ in\ different\ settlement\ level \Big/ Count\ of\ flexible\ appr} \quad (0.0$$

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 Sample Two is equal to 1.24. Thus, the use of an 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 roadway transitions to the bridge. However, the effectiveness is not significant because the ER is slightly larger than 1.

Table 0.48 Sample Two: Grade distribution for approach type in different settlement severity

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

1.20.3 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 do flexible approaches. The ordinal regression of Sample One shows that there is no association between APPT and SEVERITY. The SPSS output of Sample Two indicates that APPT is statistically significant in the relationship between APPT and SEVERITY. The ordered value of the logit equation 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 the 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 an approach slab has a positive effect on mitigating the problem caused by differential settlement at bridge ends.

1.21 Abutment Type

1.21.1 Sample One

A descriptive analysis was conducted by creating a frequency table of abutment type over settlement levels and a mosaic plot of distribution over settlement levels and 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 well and concludes that ABUT and SEVERITY are two independent variables (no association between ABUT and SEVERITY).

Table 0.49 Sample One: Frequency table of abutment type (ABUT) by SEVERITY

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

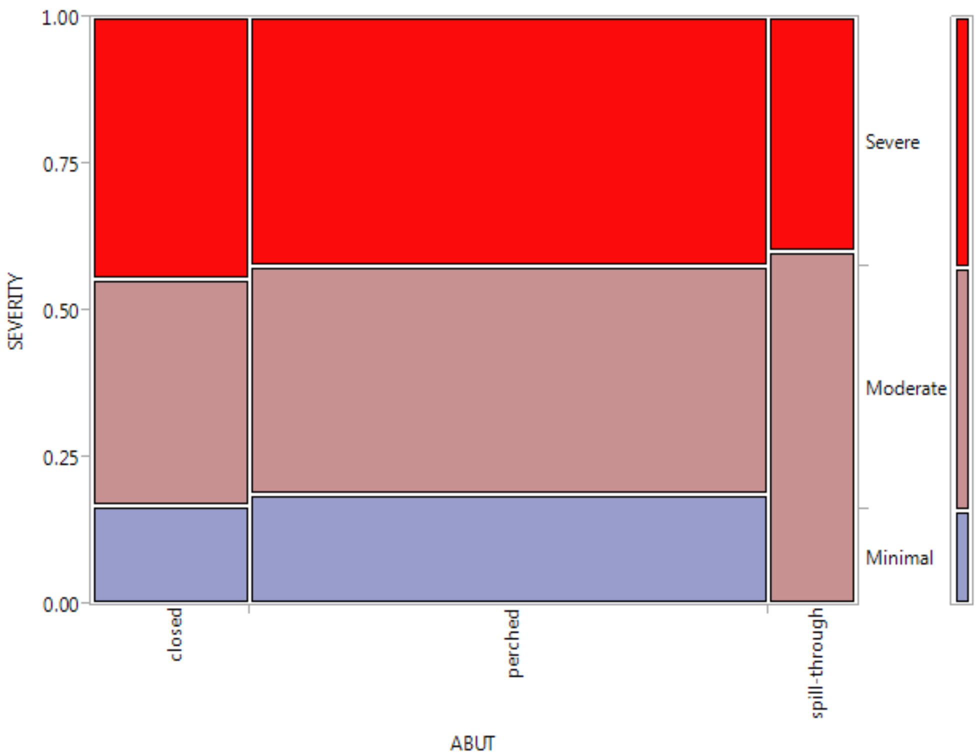


Figure 0.19 Sample One: Distribution of settlement levels across abutment type

Table 0.50 Sample One: Model fitting information of ordinal logistic regression between ABUT and SEVERITY

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	21.469			
Final	21.247	.222	2	.895

Table 0.51 Sample One: Parameter estimates of ordinal logistic regression between ABUT and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-1.596	.320	24.912	1	.000	-2.223	-.969
	[SEVERITY = 2.00]	.360	.259	1.936	1	.164	-.147	.867
Location	[ABUT=1.00]	.104	.507	.042	1	.838	-.890	1.097
	[ABUT=2.00]	.279	.650	.184	1	.668	-.994	1.552
	[ABUT=3.00]	0[a]	.	.	0	.	.	.

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

Table 0.52 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

1.21.2 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 that illustrates the distribution of SEVERITY across ABUT. It shows that bridges with perched abutments have the highest proportion of minimal settlement.

Table 0.53 Sample Two: Frequency table of abutment type (ABUT) by SEVERITY

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

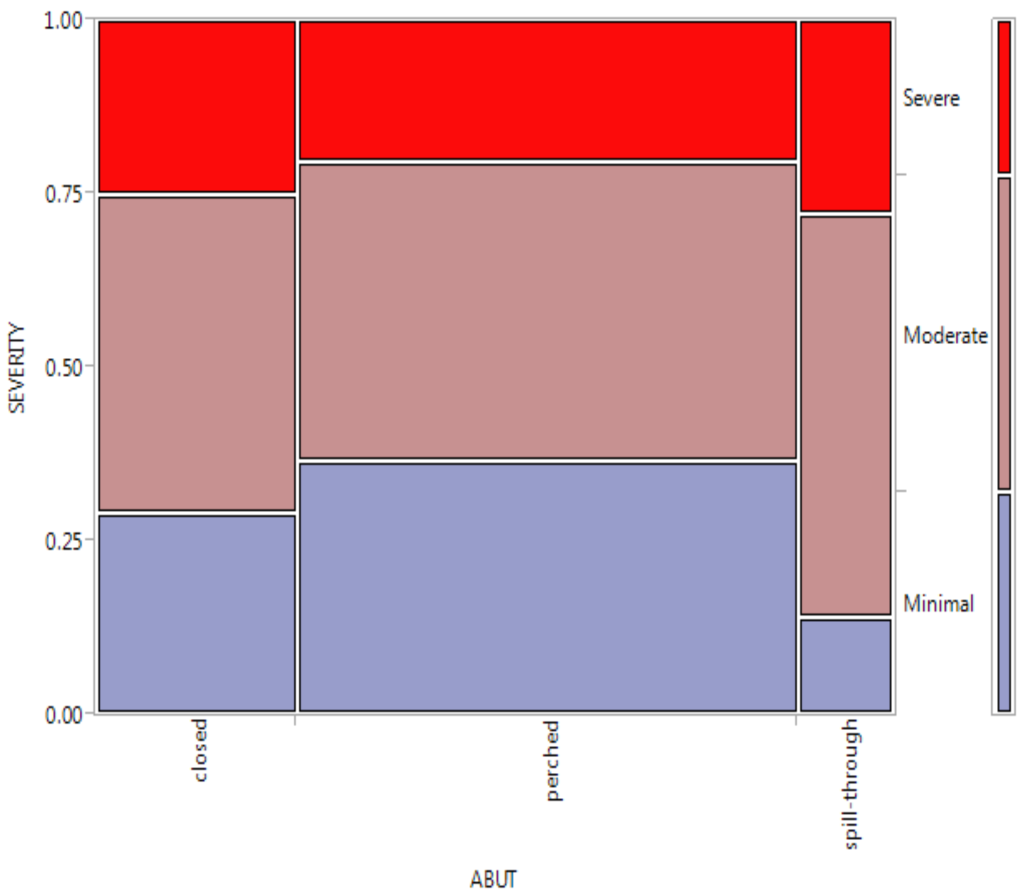


Figure 0.20 Sample Two: Distribution of settlement levels across abutment type

Table 0.54 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 0.55 Sample Two: Parameter estimates of ordinal logistic regression between ABUT and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-.589	.103	32.456	1	.000	-.792	-.386
	[SEVERITY = 2.00]	1.433	.119	145.761	1	.000	1.200	1.665
Location	[ABUT=1.00]	.320	.180	3.139	1	.076	-.034	.673
	[ABUT=2.00]	.749	.242	9.572	1	.002	.275	1.224
	[ABUT=3.00]	0[a]	.	.	0	.	.	.

Table 0.56 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 Tables 4.54 through 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 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 ABUT=3 (perched) to ABUT=2 (spill-through). In other words, the bridges with perched abutments experience a lower level of settlement compared to other types of abutment when other independent variables are the same.

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

1.21.3 Conclusions

The mosaic plots of Sample One and Sample Two both show that the bridges with perched abutments tend to present a higher proportion in minimal settlement than in other types of abutment. The SPSS output of Sample One indicates there is no association between ABUT and SEVERITY. The output of Sample Two indicates a relationship exists 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 ABUT=3 (perched) to ABUT=1 (closed), and (2) the log odds of being in a higher settlement level will increase by 0.749 if moving from ABUT=3 (perched) to ABUT=2 (spill-through).

Sample Two demonstrates that the bridges with perched abutment experience a lower level of settlement compared to other types of abutment when other independent variables are the same.

1.22 Embankment Height

1.22.1 Sample One

A scatterplot of approach settlement levels by embankment height of Sample One is shown 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 the four categories defined in Table 4.57. The EHG of 0-20 feet shows a higher proportion of minimal settlement than the group of above 20 feet. EHG of above 20 feet shows a higher proportion of severe settlement than the group of 0~20 feet. The output from SPSS shows in the null hypothesis that the model regression coefficient is equal to zero, and 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.

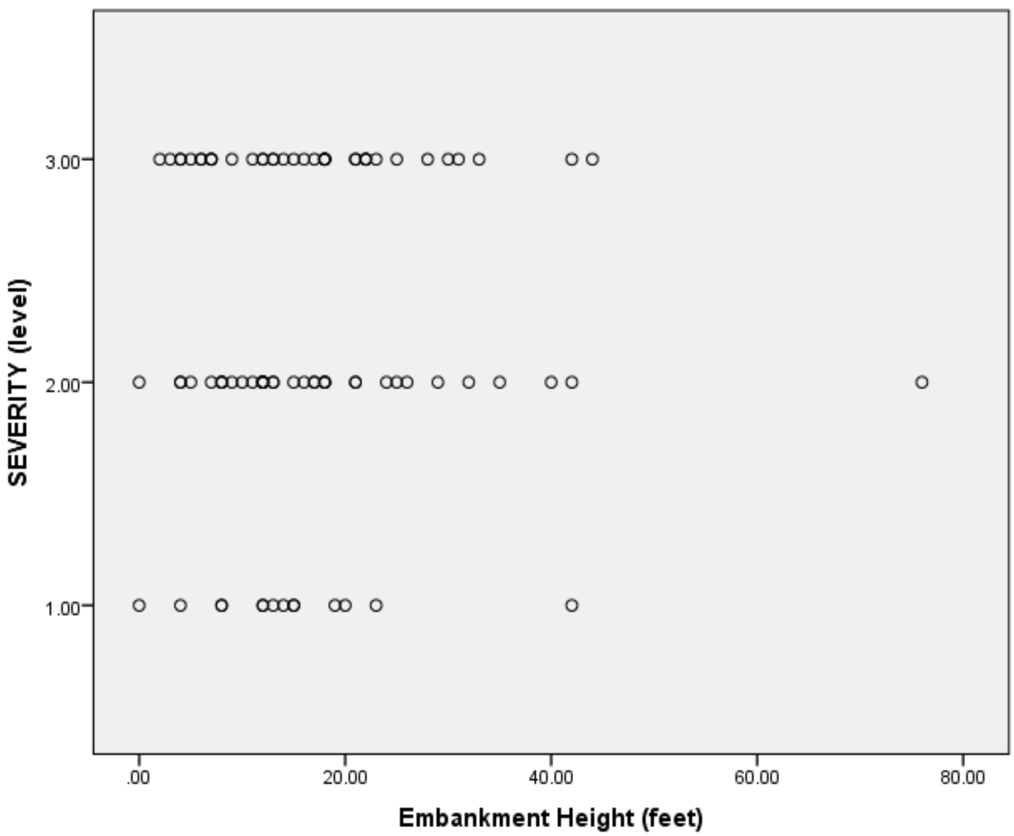


Figure 0.21 Sample One: Scatterplot of approach settlement levels by embankment height

Table 0.57 Sample One: Frequency table of embankment height group (EHG) by SEVERITY

EH group (feet)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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 0.58 Sample One: Model fitting information of ordinal logistic regression between EH and SEVERITY

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

Table 0.59 Sample One: Parameter estimates of ordinal logistic regression between EH and SEVERITY

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

Table 0.60 Sample One: Test of parallel lines of ordinal logistic regression between EH and SEVERITY

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

1.22.2 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 minimal settlement than the other groups. EHG above 20 feet shows a higher proportion of severe settlement than the group of 0-20 feet. The output from SPSS shows in the null hypothesis that the model regression coefficient is equal to zero, and 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, after considering all other independent variables.

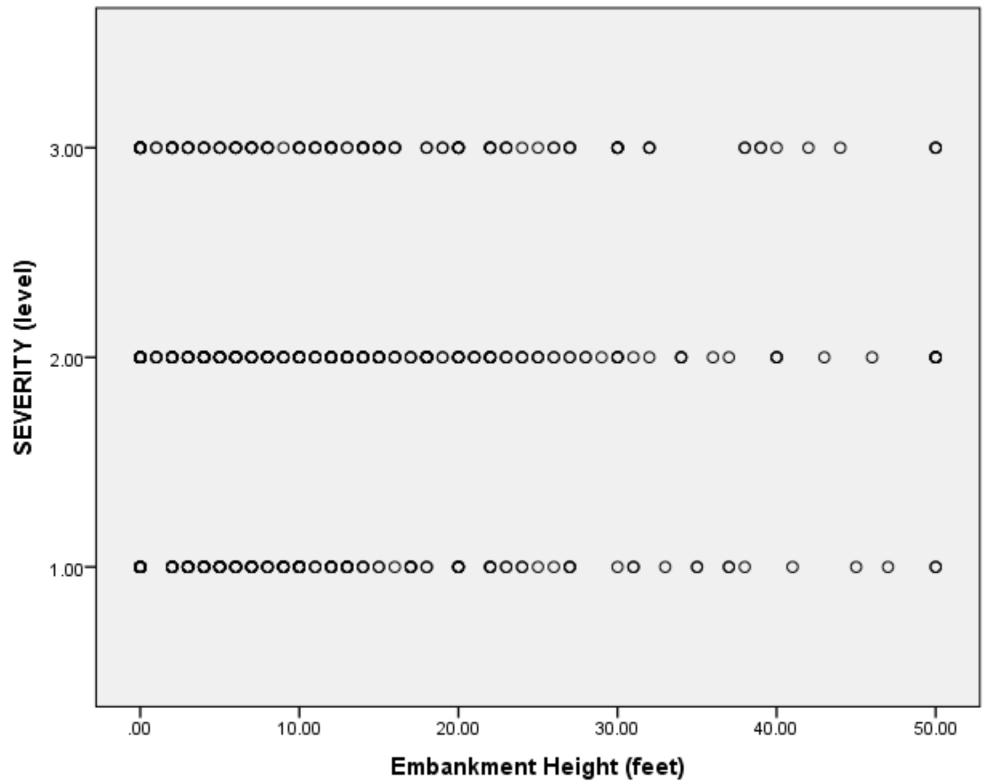


Figure 0.22 Sample Two: Scatterplot of approach settlement levels by embankment height

Table 0.61 Sample Two: Frequency table of embankment height group (EHG) by SEVERITY

EH group (feet)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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 0.62 Sample Two: Model fitting information of ordinal logistic regression between EH and SEVERITY

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

Table 0.63 Sample Two: Parameter estimates of ordinal logistic regression between EH and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-.512	.119	18.577	1	.000	-.745	-.279
	[SEVERITY = 2.00]	1.502	.134	125.068	1	.000	1.239	1.766
Location	EH	.021	.007	8.846	1	.003	.007	.034

Table 0.64 Sample Two: Test of parallel lines of ordinal logistic regression between EH and SEVERITY

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

1.22.3 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. Both samples show that shallow embankment tend to settle less than deep embankment. The group of above 30 feet presents the highest proportion of approaches with severe settlement for Sample One and the group of 21-30 feet presents the highest proportion of approaches with severe settlement for Sample Two. Both samples show that deep embankments tend to settle more than shallow embankments.

The SPSS output for Sample One and Sample Two are different. The model of Sample Two better reflects 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 that 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.

1.23 Foundation Soil Depth

1.23.1 Sample One

A scatterplot of approach settlement levels by foundation soil depth is shown 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 minimal settlement 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.

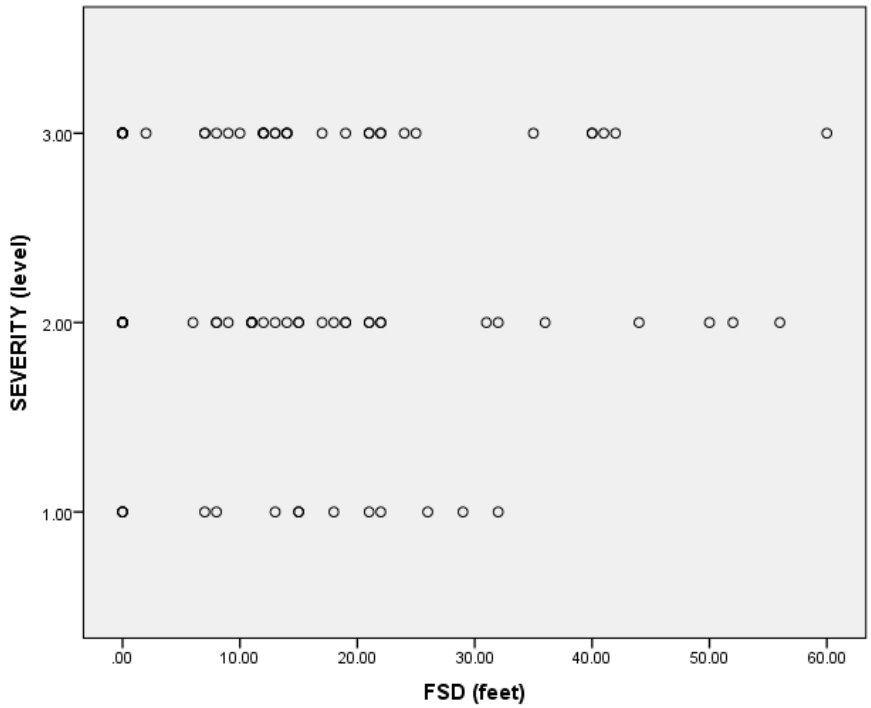


Figure 0.23 Sample One: Scatterplot of approach settlement levels by foundation soil depth

Table 0.65 Sample One: Frequency table of foundation soil depth (FSD) by SEVERITY

FSD (feet)	Severity			Total	Mean	
	Minimal	Moderate	Severe		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		

Table 0.66 Sample One: Model fitting information of ordinal logistic regression between FSD and SEVERITY

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

Table 0.67 Sample One: Parameter estimates of ordinal logistic regression between FSD and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-1.635	.370	19.550	1	.000	-2.359	-.910
	[SEVERITY = 2.00]	.318	.315	1.017	1	.313	-.300	.936
Location	FSD	.001	.014	.005	1	.942	-.027	.029

Table 0.68 Sample One: Test of parallel lines of ordinal logistic regression between FSD and SEVERITY

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

1.23.2 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 by 0.018.

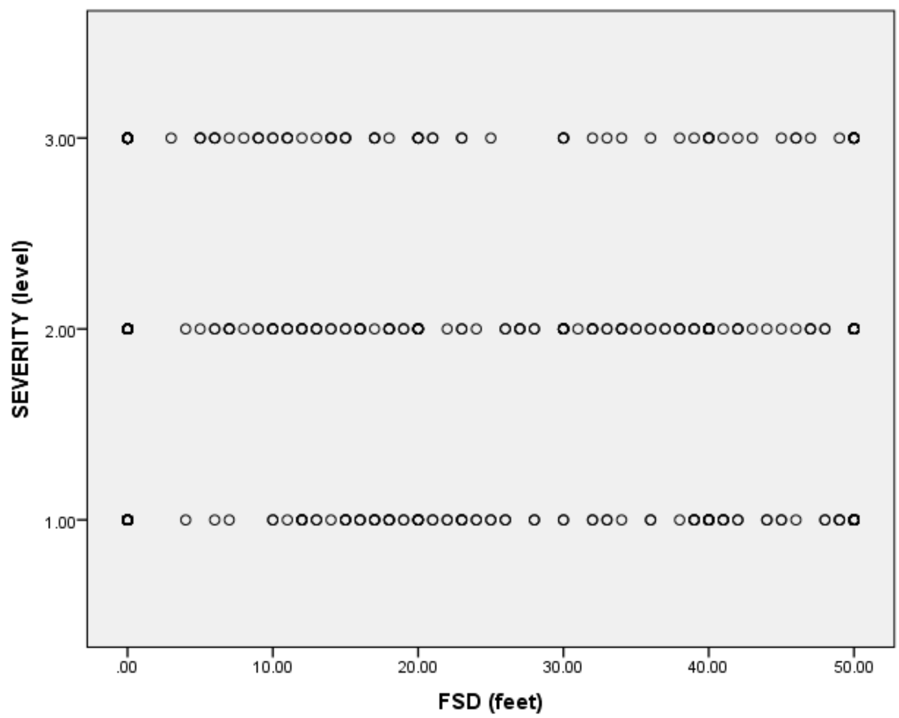


Figure 0.24 Sample Two: Scatterplot of approach settlement levels by foundation soil depth

Table 0.69 Sample Two: Frequency table of foundation soil depth (FSD) by SEVERITY

FSD (feet)	Severity			Total	Mean	
	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		

Table 0.70 Sample Two: Model fitting information of ordinal logistic regression between FSD and SEVERITY

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

Table 0.71 Sample Two: Parameter estimates of ordinal logistic regression between FSD and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[SEVERITY = 1.00]	-1.137	.124	84.670	1	.000	-1.379	-.895
	[SEVERITY = 2.00]	.910	.120	57.677	1	.000	.675	1.145
Location	FSD	-.018	.004	20.797	1	.000	-.026	-.010

Table 0.72 Sample Two: Test of parallel lines of ordinal logistic regression between FSD and SEVERITY

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

1.23.3 Conclusions

Descriptive analysis of Sample One indicates that shallow foundations tend to have a lower level of settlement compared to deep foundations. 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 Sample Two shows that for a one unit increase in FSD, a 0.018 decrease in the ordered log odds of having 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.

1.24 Foundation Soil Consistency

1.24.1 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 having minimal settlement varies slightly in each of soil consistency group. In 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 0.73 Sample One: Frequency table of foundation soil consistency (FSC) by SEVERITY

FSC (level)	Severity			Total
	Minimal	Moderate	Severe	
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

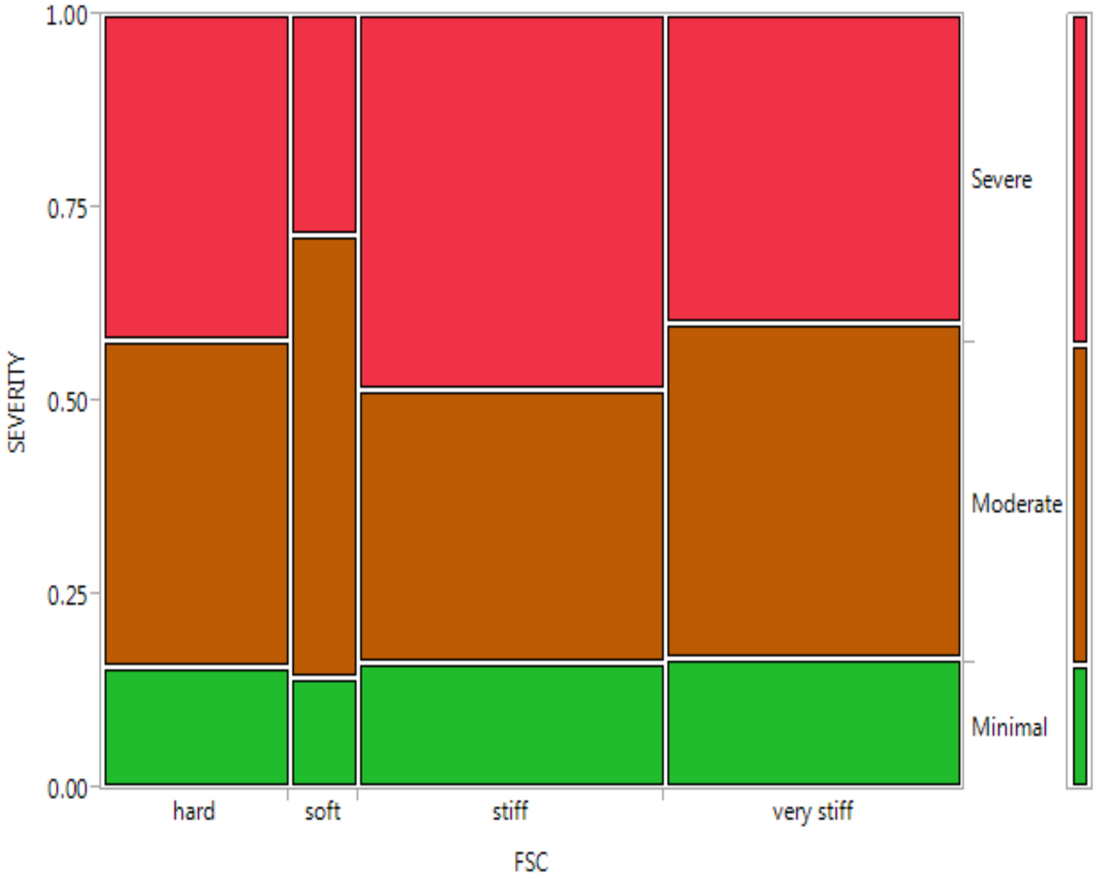


Figure 0.25 Sample One: Distribution of settlement levels across foundation soil consistency

Table 0.74 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 0.75 Sample One: Parameter estimates of ordinal logistic regression between FSC and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							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
Location	[FSC=1.00]	-.339	.827	.168	1	.682	-1.960	1.283
	[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	.	.	.

Table 0.76 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

1.24.2 Sample Two

The mosaic plot of settlement levels across foundation soil consistency shows that the group of hard foundation soil consistency has the lowest proportion of minimal settlement but has the highest proportion of 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 equation predicts that higher settlement odds will decrease by 0.432 if moving from FSC=4 (hard) to FSC=1 (soft). The logit equation predicts that higher settlement odds will decrease by 0.494 if moving from FSC=4 (hard) to FSC=2 (stiff). The logit equation predicts that higher settlement odds 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 0.77 Sample Two: Frequency table of foundation soil consistency (FSC) by SEVERITY

FSC (level)	Severity			Total
	Minimal	Moderate	Severe	
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

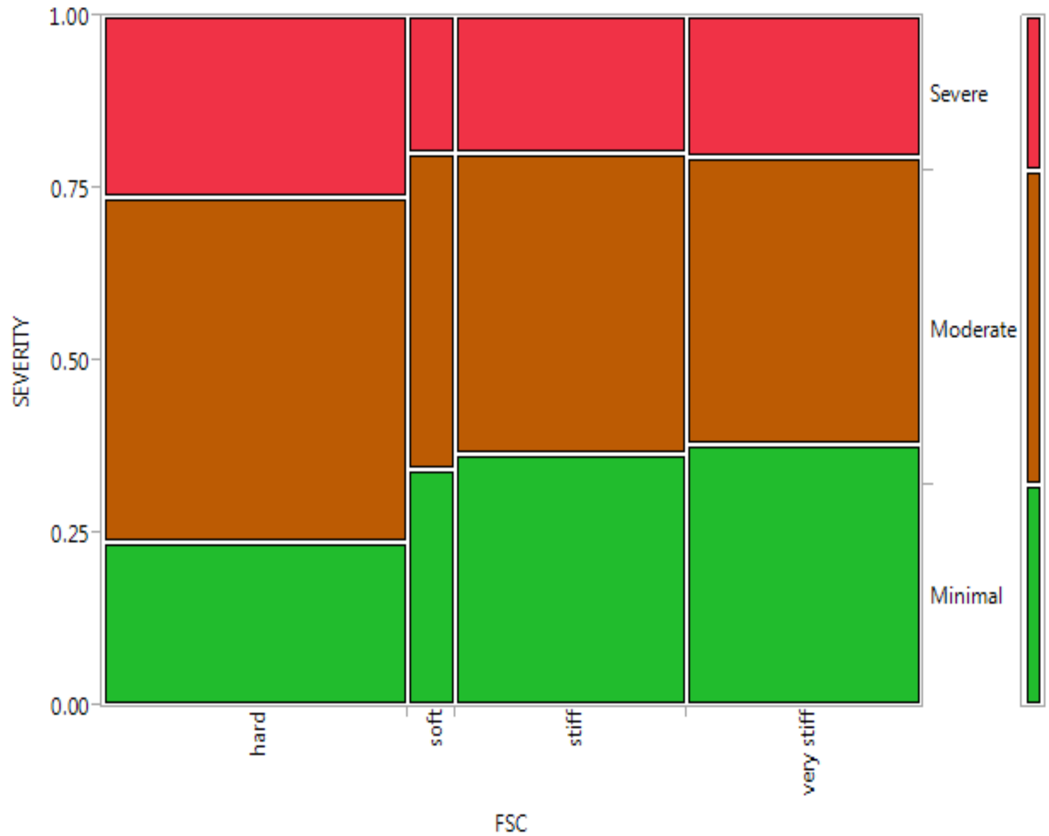


Figure 0.26 Sample Two: Distribution of settlement levels across foundation soil consistency

Table 0.78 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 0.79 Sample Two: Parameter estimates of ordinal logistic regression between FSC and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							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
Location	[FSC=1.00]	-.432	.340	1.614	1	.204	-1.099	.235
	[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	.	.	.

Table 0.80 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

1.24.3 Conclusions

The descriptive analysis of Sample One and Sample Two cannot provide a clear picture of the relationship between FSC and SEVERITY. The ordinal logistic regression of Sample One shows that there is no association between FSC and SEVERITY, while 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 of minimal settlement but has the highest proportion of 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.

1.25 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 there is a 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 district one and district ten behave much better than other districts with the highest proportion of minimal settlement and the lowest proportion of severe settlement.

Table 0.81 Distribution of the Bridge Approaches from Each District

District	Sample One				Sample Two			
	Severity			Total	Severity			Total
	Minimal	Moderate	Severe		Minimal	Moderate	Severe	
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

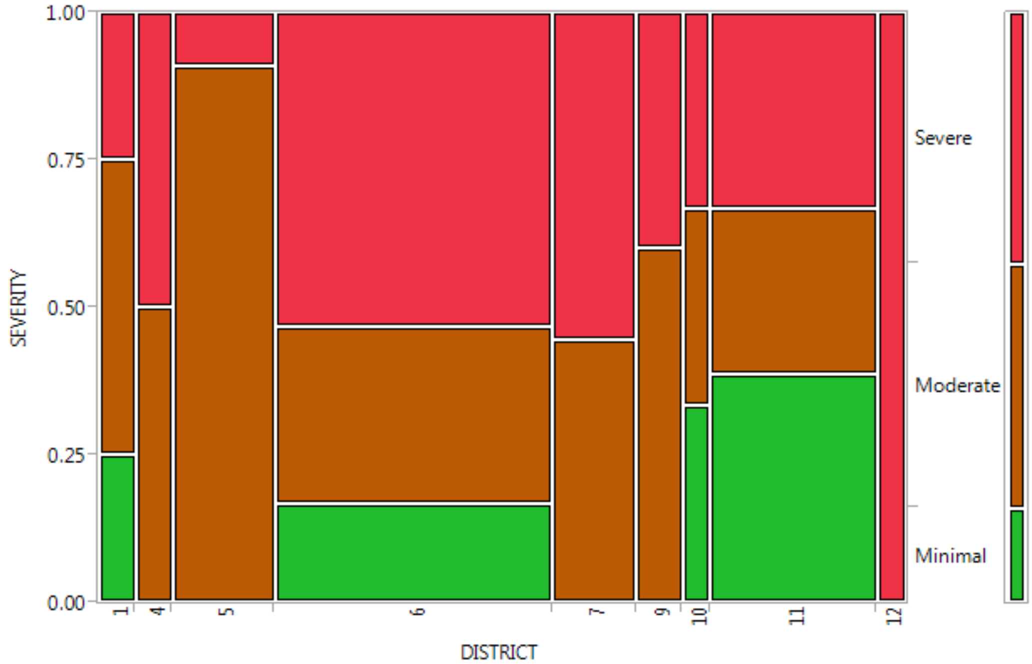


Figure 0.27 Sample One: Distribution of settlement levels across transportation district

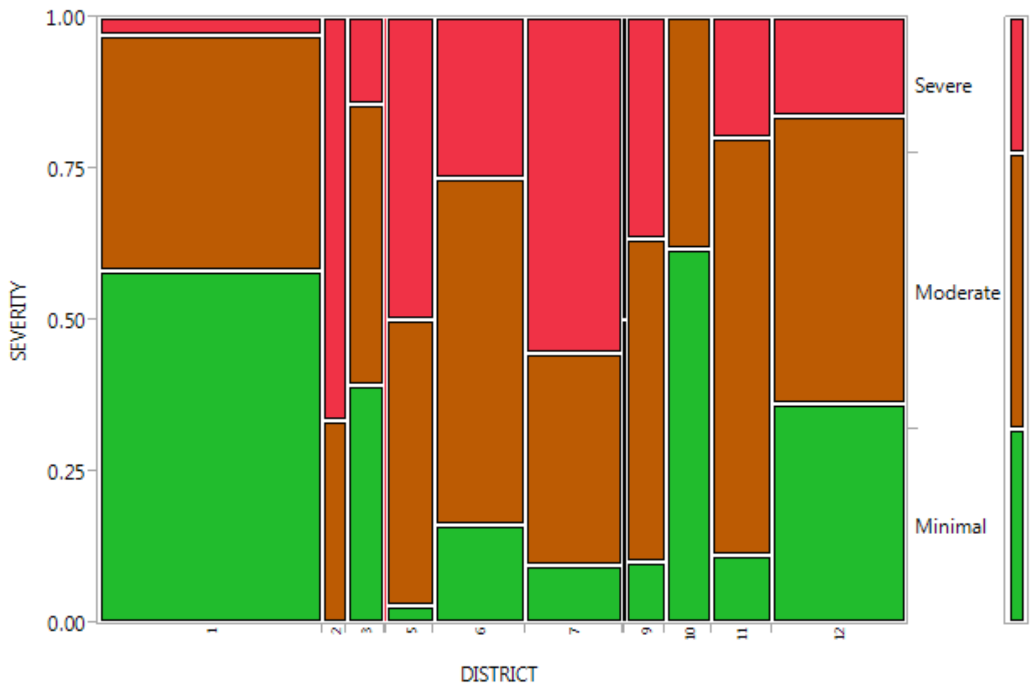


Figure 0.28 Sample Two: Distribution of settlement levels across transportation district

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 is violated, shown by the slope coefficients being the same across response categories. 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 0.82 Sample One: Test of parallel lines of ordinal logistic regression between DISTRICT and SEVERITY

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

Table 0.83 Sample One: Model fitting information of multinomial logistic regression between district and SEVERITY

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	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 0.84 Sample One: Parameter estimates of multinomial logistic regression between DISTRICT and SEVERITY

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

Note: The reference category is: 3.00

Table 0.85 Sample One: Parameter estimates of multinomial logistic regression between DISTRICT and SEVERITY

Observed	Predicted			
	1.00	2.00	3.00	Percent 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 p-value of the model is slightly larger than 0.05. It is uncertain if 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 0.86 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

Table 0.87 Sample Two: Parameter estimates of ordinal logistic regression between DISTRICT and SEVERITY

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper 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
Location	[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
	[DISTRICT=6.00]	.961	.312	9.506	1	.002	.350	1.572
	[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 0.88 Sample Two: Test of parallel lines of ordinal logistic regression between DISTRICT and SEVERITY

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

The model from the ordinal logistic regression for Sample Two is statistically significant. There is a significant relationship between DISTRICT and SEVERITY. The ordered log-odds regression coefficients were obtained by comparing to DISTRICT=12. There are three districts (district one, three, and ten) that 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 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 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 DISTRICT=12 to DISTRICT=10.

1.26 Comprehensive Model

Based on the above analyses between each parameter and dependent variable, 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 before interpreting the SPSS output. For each categorical variable with K levels, K-1 dummy variables should be assumed. Dummy variables in this study are defined in Table 4.90. According to different probability theory, the output form of the models from ordinal logistic regression and multinomial logistic regression are different. Proportional-odds cumulative logit model is possibly the most popular model for ordinal data. This model uses cumulative probabilities up to 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 should be developed for ordinal logistic regression.

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

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

$$\pi_1 + \pi_2 + \pi_3 = 1 \quad (4.14)$$

Therefore,

$$\pi_1 = \frac{\exp\left(-\alpha_1 + \beta_1 x_1 + \cdots + \beta_{10} x_{10}\right)}{1 + \exp\left(-\alpha_1 + \beta_1 x_1 + \cdots + \beta_{10} x_{10}\right)} \quad (4.15)$$

$$\pi_2 = \frac{\exp\left(-\alpha_1 + \beta_1 x_1 + \cdots + \beta_{10} x_{10}\right)}{1 + \exp\left(-\alpha_1 + \beta_1 x_1 + \cdots + \beta_{10} x_{10}\right)} - \pi_1 \quad (4.16)$$

$$\pi_3 = 1 - \pi_1 - \pi_2 \quad (4.17)$$

When the assumption states that the slope coefficients in the model are the same across response categories for ordinal logistic regression, and are rejected, a less restrictive model of multinomial logistic regression is an optimal method. Multinomial logistic regression models how a 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.

$$Logit\frac{\pi_1}{\pi_3} = \alpha_1 + \beta_{11} x_1 + \cdots + \beta_{110} x_{10} \quad (4.18)$$

$$Logit\frac{\pi_2}{\pi_3} = \alpha_2 + \beta_{21} x_1 + \cdots + \beta_{210} x_{10} \quad (4.19)$$

$$\pi_1 + \pi_2 + \pi_3 = 1 \quad (4.20)$$

Table 0.89 Classification of the variables in the model

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

Table 0.90 Dummy variables definition in the model

DISTRICT	ABUT

Original	Dummy	Original	Dummy
District1=1; District2=2; District3=3; District4=4; District5=5; District6=6; District7=7; District8=8; District9=9; District10=10; District11=11; District12=12	DIS1=1, otherwise DIS1=0; DIS2=1, otherwise DIS2=0; DIS3=1, otherwise DIS3=0; DIS4=1, otherwise DIS4=0; DIS5=1, otherwise DIS5=0; DIS6=1, otherwise DIS6=0; DIS7=1, otherwise DIS7=0; DIS8=1, otherwise DIS8=0; DIS9=1, otherwise DIS9=0; DIS10=1, otherwise DIS10=0; DIS11=1, otherwise DIS11=0; All DIS=0	Perched=1; Closed=2; Spill- through=3	ABUT1=1, otherwise ABUT1=0; ABUT2=1, otherwise ABUT2=0; All ABUT=0
APPT		FSC	
Original	Dummy	Original	Dummy
Flexible=1; Rigid=2	APPT1=1, otherwise APPT1=0; All APPT=0	Soft=1; Stiff=2; Very stiff=3; Hard=4	FSC1=1, otherwise FSC1=0; FSC2=1, otherwise FSC2=0; FSC3=1, otherwise FSC3=0; All FSC=0

1.26.1 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 0.91 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 0.92 Sample One: Goodness of fit of ordinal logistic regression

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

Table 0.93 Sample One: Pseudo R-square of ordinal logistic regression

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

Table 0.94 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 for 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 units 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 units 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 foot, the multinomial log odds of being minimal relative to severe would be expected to decrease by 0.175 units 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 units 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 units 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 foot, the multinomial log odds of being minimal relative to severe would be expected to decrease by 0.004 units while holding all other variables in the model constant.

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

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

$$\begin{aligned} logit\frac{\pi_2}{\pi_3} = {} & -4.972 + 0.000LENGTH + 0.021WIDTH + 0.014AGE + 0.000ADT \\ & - 0.016EH - 0.004FSD + 18.093DIS1 + 0.000DIS2 + 0.000DIS3 \\ & + 16.967DIS4 + 19.462DIS5 + 16.612DIS6 + 17.134DIS7 + 0.000DIS8 \\ & + 17.776DIS9 + 17.041DIS10 + 16.859DIS11 + 0.000DIS12 \\ & - 13.840ABUT1 - 0.075ABUT2 + 0.000ABUT3 + 0.898APPT1 \\ & + 0.000APPT2 - 13.082FSC1 - 14.185FSC2 - 13.552FSC3 \\ & + 0.000FSC4 \quad (4.22) \end{aligned}$$

The probability relationship between three severity levels:

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

By using the equations above, the probability that each settlement category may occur based on all predictors can be computed. 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 correctly predicting the settlement levels is 67.8%.

Table 0.95 Sample One: Model fitting information of multinomial logistic regression

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

Table 0.96 Sample One: Goodness of fit of ordinal logistic regression

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

Table 0.97 Sample One: Pseudo R-square of multinomial logistic regression

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

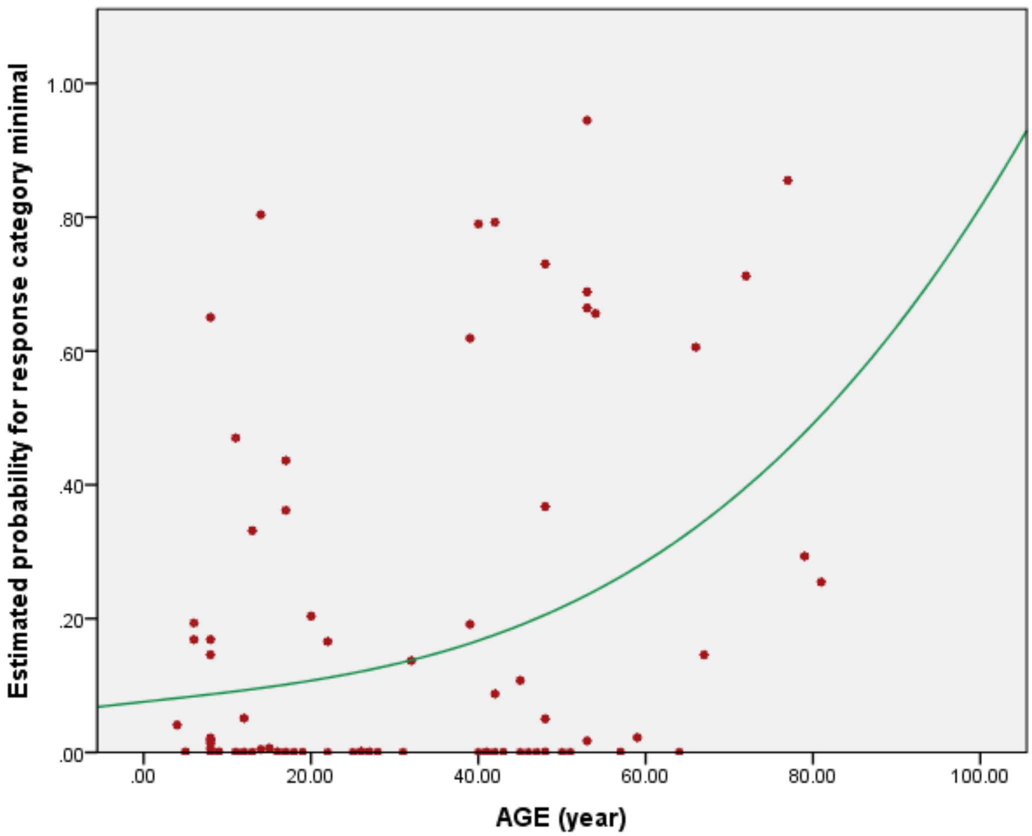
Table 0.98 Sample One: Likelihood ration tests of multinomial logistic regression

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-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 0.99 Sample One: Classification table of multinomial logistic regression

Observed	Predicted			
	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%

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 minimal settlement level 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 minimal settlement level than do other districts. Similarly, the variation trend of the estimated probability of minimal versus foundation soil depth indicates that the probability of being in the minimal settlement level 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 0.29 Sample One: Variation trend of the estimated probability of minimal settlement versus approach age

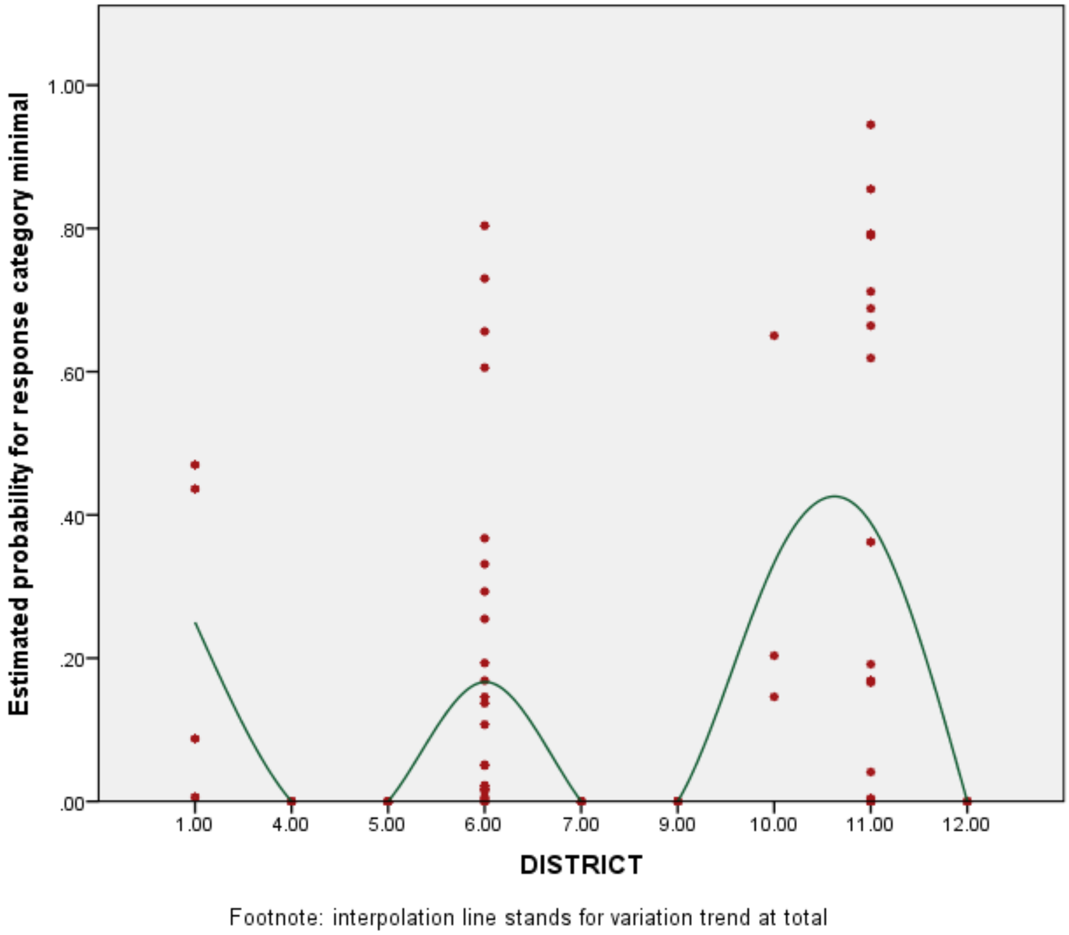


Figure 0.30 Sample One: Variation trend of the estimated probability of minimal settlement versus transportation districts

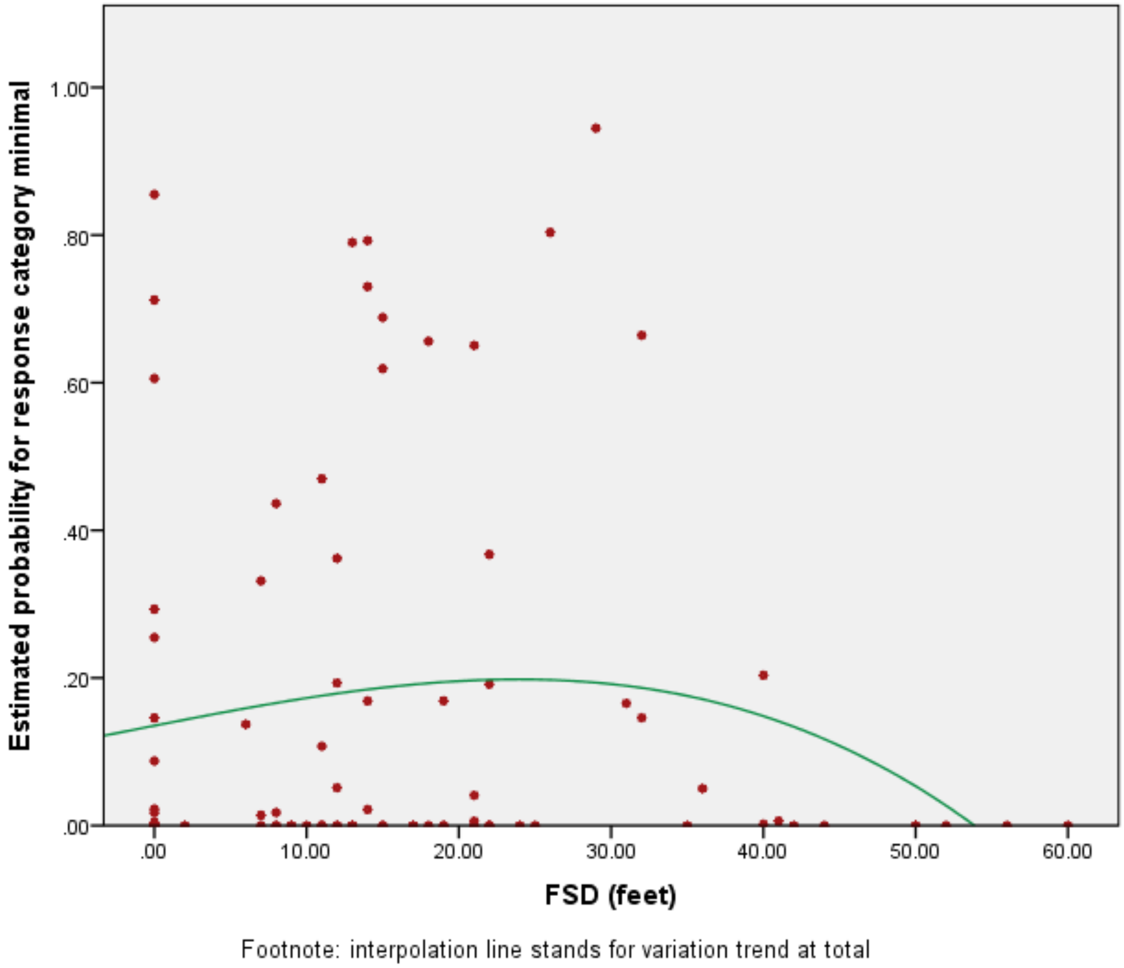


Figure 0.31 Sample One: Variation trend of the estimated probability of minimal settlement versus foundation soil depth

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 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 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.

1.26.2 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. The 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 Tables 4.100 through 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 can 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 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 conclude that the log odds of being in a higher level of settlement severity will decrease by 1.124 if moving from 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 log-odds 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 units 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 the flexible approach while the other variables in the model are held constant.

Table 0.100 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 0.101 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 0.102 Sample Two:: Pseudo R-square of multinomial logistic regression

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

Table 0.103 Sample Two: Likelihood ratio tests of multinomial logistic regression

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 0.104 Sample Two: Classification table of multinomial logistic regression

Observed	Predicted			
	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:

$$
\begin{aligned}
logit\frac{\pi_1}{\pi_3} = {} & 4.624 - 0.001LENGTH - 0.015WIDTH - 0.29AGE + 1.0\times10^{-8}ADT - 0.006EH \\
& - 0.003FSD + 2.278DIS1 - 18.812DIS2 + 0.452DIS3 - 20.848DIS4 - 3.749DIS5 \\
& - 0.980DIS6 - 2.714DIS7 - 17.614DIS8 - 2.427DIS9 + 16.495DIS10 \\
& - 1.356DIS11 + 0.000DIS12 - 0.749ABUT1 - 1.246ABUT2 + 0.000ABUT3 \\
& - 0.977APPT1 + 0.000APPT2 - 0.188FSC1 - 0.718FSC2 - 1.026FSC3 \\
& + 0.000FSC4 \qquad (4.24)
\end{aligned}
$$

$$logit\frac{\pi_2}{\pi_3} = 2.423 + 0.000LENGTH + 0.002WIDTH - 0.009AGE + 1.2\times10^{-8}ADT - 0.005EH + 0.007FSD + 1.549DIS1 - 1.907DIS2 + 0.176DIS3 - 20.103DIS4 - 0.969DIS5 - 0.140DIS6 - 1.580DIS7 - 1.072DIS8 - 0.830DIS9 + 15.721DIS10 + 0.193DIS11 + 0.000DIS12 - 0.319ABUT1 - 0.082ABUT2 + 0.000ABUT3 - 0.525APPT1 + 0.000APPT2 - 0.383FSC1 - 0.662FSC2 - 0.846FSC3 + 0.000FSC4 \quad (4.25)$$

The probability relationship between three severity levels:

$$\pi_1 + \pi_2 + \pi_3 = 1 \qquad (4.26)$$

By using these three equations above, the probability that each settlement category may occur based on all predictors may be computed. 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 correctly predicting the settlement levels by using this model is 60.5%. ‘

As in 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 minimal settlement level than other districts. From the variation trend of the estimated probability of minimal versus approach age, the probability of being in the minimal settlement level 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 minimal settlement will decrease as the average daily traffic increases. Furthermore, it may be concluded that rigid approaches tend to have a higher probability of experiencing minimal settlement levels than flexible approaches.

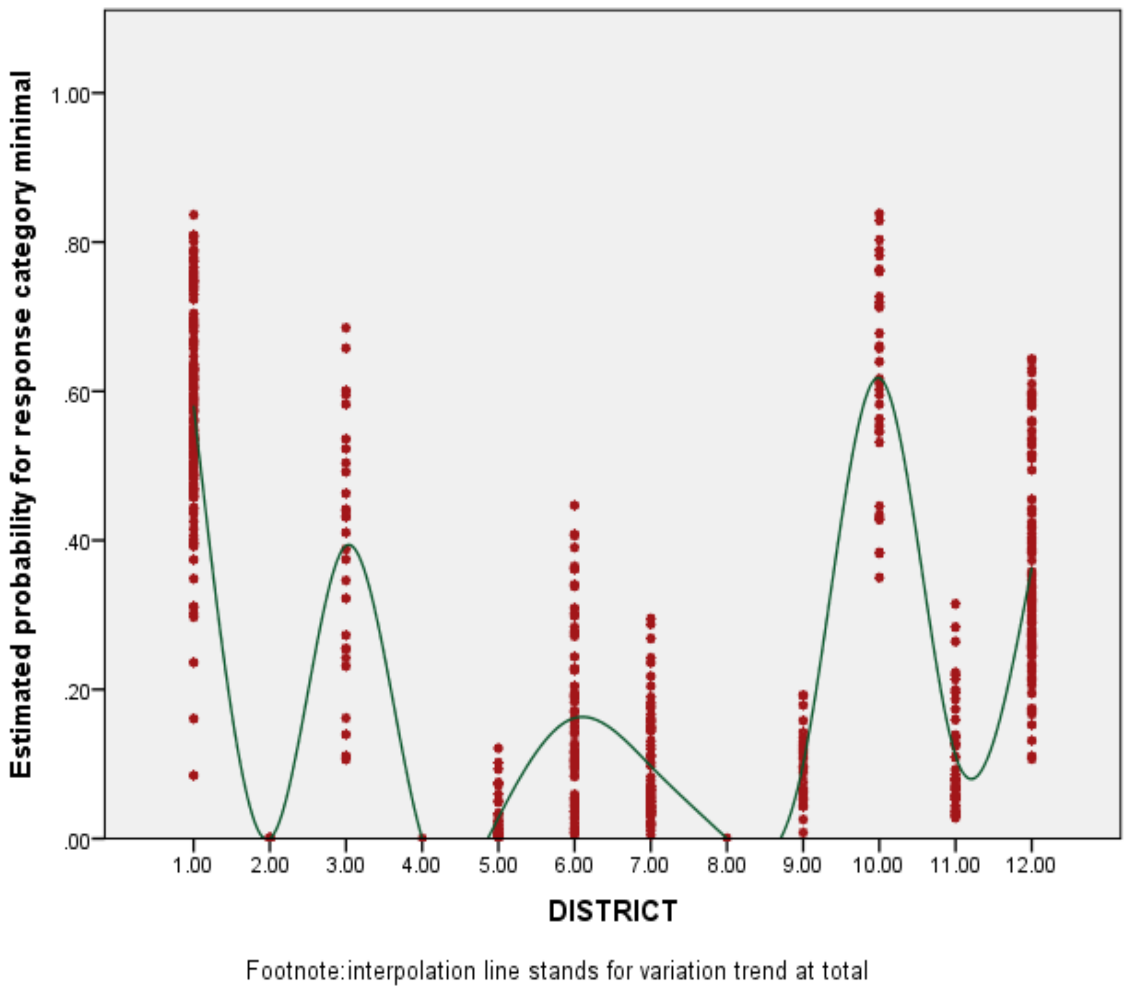
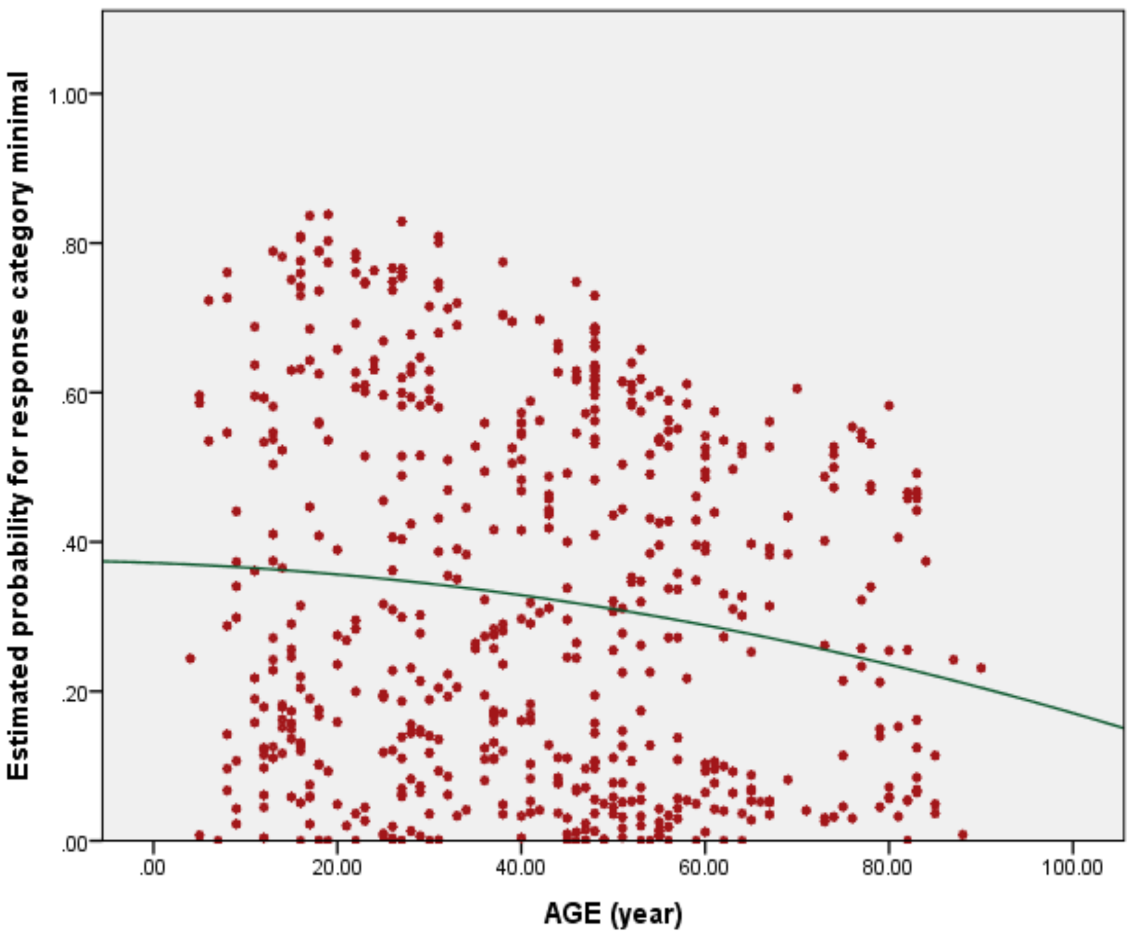
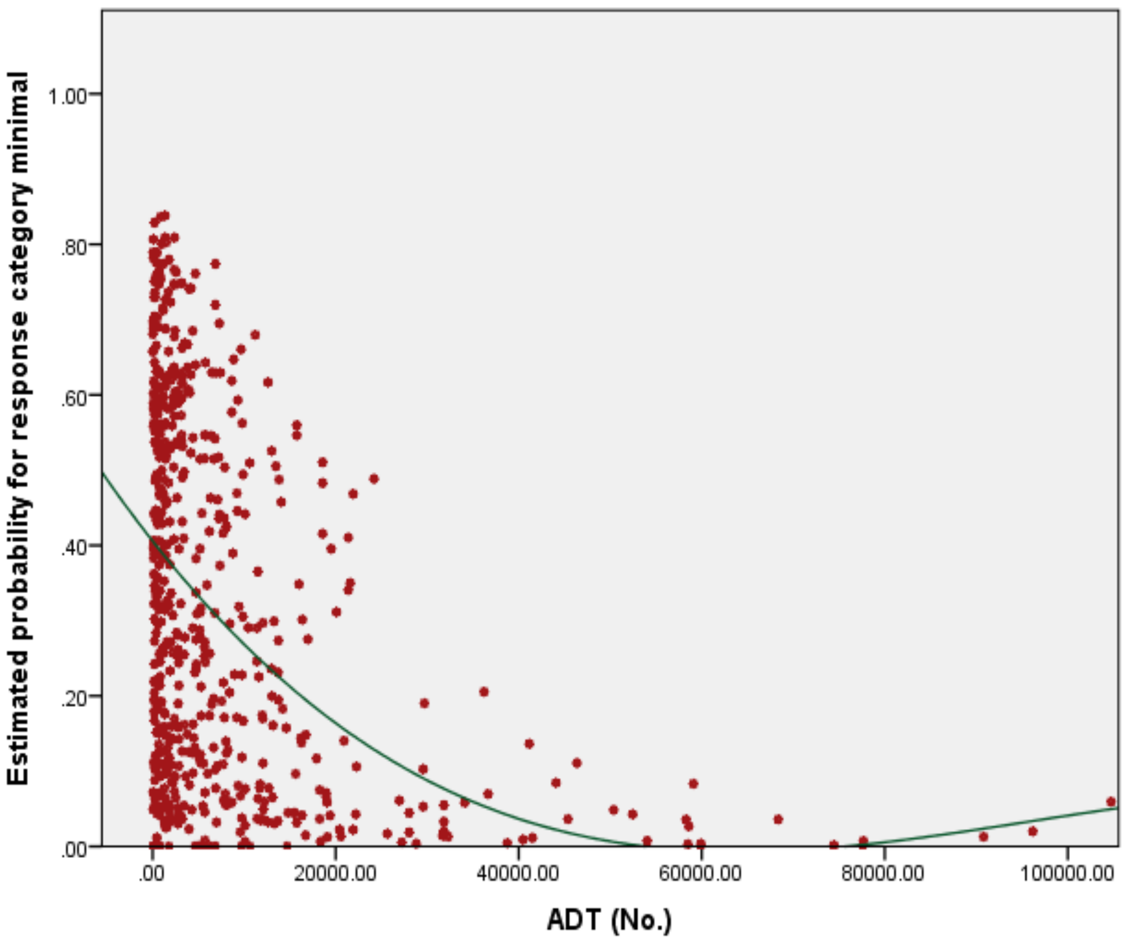


Figure 0.32 Sample Two: Variation trend of the estimated probability of minimal settlement versus transportation districts



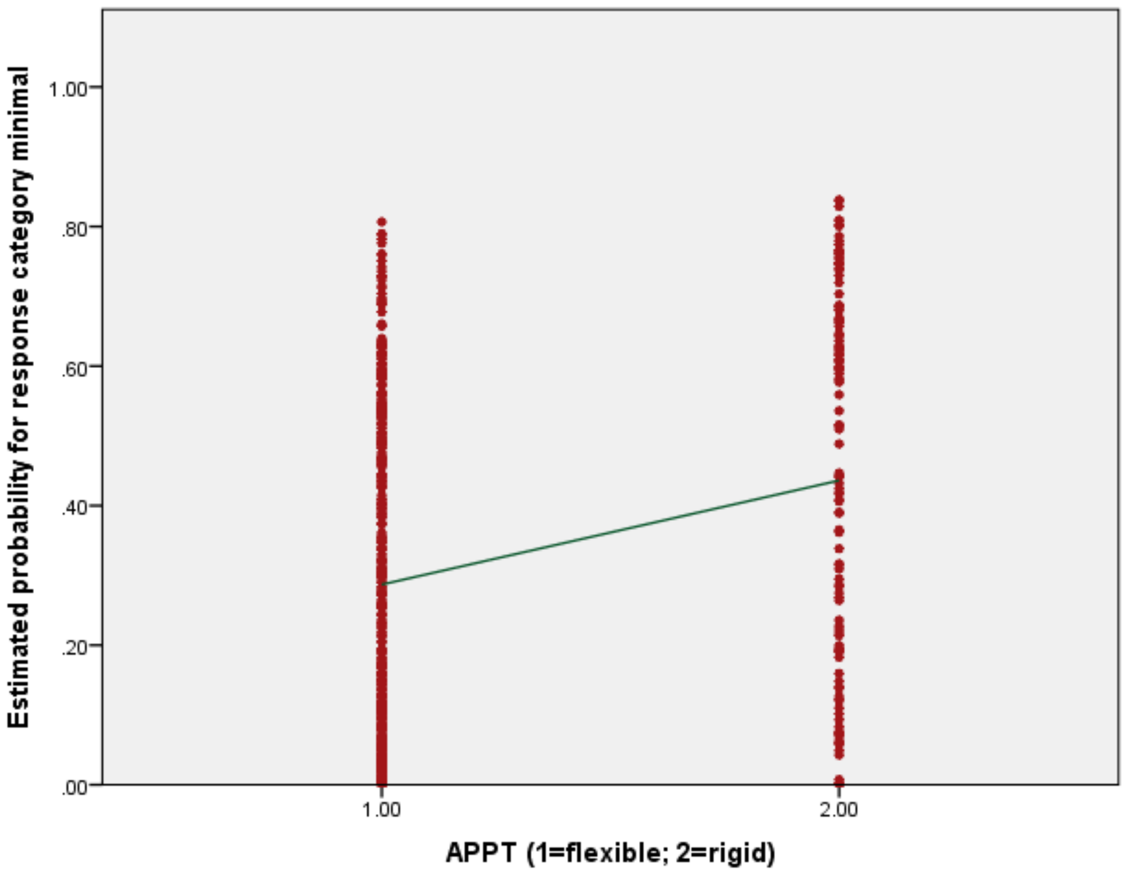
Footnote: interpolation line stands for variation trend at total

Figure 0.33 Sample Two: Variation trend of the estimated probability of minimal settlement versus approach age



Footnote: interpolation line stands for variation trend at total

Figure 0.34 Sample Two: Variation trend of the estimated probability of minimal settlement versus average daily traffic



Footnote: interpolation line stands for variation trend at total

Figure 0.35 Sample Two: Variation trend of the estimated probability of minimal settlement 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 can be concluded:

- The performance of approaches in 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.

1.26.3 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. The method in this section used the utility named Scoring Wizard in SPSS to apply the model created with Sample One to dataset of Sample Two, generated the predicted settlement category, and conversely applied the model created with Sample Two to a dataset of Sample One. The scoring process consists of three basic steps:

1. 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 should be in hand.
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; 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 a 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 a 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 based on preferred requirements and purposes.

Table 0.105 Percent correct of applying two models to the other dataset

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

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.

1.26.4 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 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 compared 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.

DISTRICT INTERVIEWS

The research team visited five of KYTC's twelve districts to document problems with bridge approaches. Bridge engineers in design, construction, and maintenance from District 1, District 3, District 5, District 11, and District 12 were interviewed in-person or using a video conferencing service. This section summarizes the practices KYTC district personnel have adopted to mitigate settlement at bridge approaches. It also discusses recommended methods to alleviate and manage settlement that occurs at bridge approaches. Current practices and recommended treatments are broken down based on their focus: foundation soil, backfill materials, approach slab, abutments, and drainage.

This section provides bridge engineers the corrective measures that can be applied when differential settlement is predicted to occur. Bridge designers can use the models outlined in Chapter 4 to predict the magnitude of approach settlement based on foundation, approach, embankment, and other variables, and then apply corrective techniques or measures to prevent or minimize the settlement problems that may occur in the future. Alternatively, bridge maintenance engineers can use these models to predict approach settlement level for a bridge that has already been constructed and then implement maintenance measures based on the approach's level of distress.

1.27 Foundation Soil

Foundation soils beneath the embankment and embankment fill are influences on the performance of bridge approaches (Wahls, 1990). Many studies have demonstrated that the settlement mechanism and process is contingent on soil type. For granular soils, such as sand, gravel, and rock, settlement occurs rapidly, however, in many cases the differential settlement between roadway and bridge upper structure is negligible. For cohesive soils, the settlement process is more drawn out. Settlement either from primary and/or secondary consolidation settlement may emerge over the long-term. The settlement of foundation soils and embankment fill may lead to a poor performance of bridge approaches. Generally, the time period for the primary settlement phase ranges from a few months in very granular soils to 7–10 years for some clays (Hopkins, 1973).
Accordingly, mitigation strategies must be tailored to the type of foundation soil which supports a bridge.

Predictive models developed from Sample 1 and Sample 2 indicated that there was no significant relationship between the type of foundation soil and the magnitude of approach settlement. However, the research team cannot infer from this that foundation soils do not influence how much bridge approach settlement takes place. It is critical to note that the information on foundation soils used to populate the model represented the condition of the soils after they had been improved or received special treatments (especially for highly compressible foundation soils). Appropriate treatment methods or measures for highly compressible foundation soils are necessary before the construction of bridge components. Therefore, a full investigation of local foundation soils is needed before design and construction begins. Table 5.1 summarizes the improvement/treatment techniques or measures which were applied based on soil type. According to the function of each stabilization technique, Puppala (2009) divided these techniques into three subcategories, which are summarized in Table 5.2.

Table 0.1 Summary of foundation soils improvement methods based on soil type

Technique	Granular soils	Cohesive soils
Excavation and replacement	✘	✔
Preloading with or without surcharge	✔	✔
Dynamic compaction	✔	✔
Grouting	✔	✔

Drains	✘	✔
Grave/Stone columns	✘	✔
Geosynthetics	✔	✔

Table 0.2 Summary of foundation soils improvement methods based on soil type based on the function (Puppala, 2009)

<table>
<tr><td>Mechanical</td><td>Hydraulic</td><td>Reinforcement</td></tr>
<tr><td rowspan="3">Excavation and replacement;
Preloading and surcharge;
Dynamic compaction</td><td rowspan="3">Sand drains;
Prefabricated drains;
Surcharge loading</td><td>Columns:
Stone and lime columns;
Geopiers;
Concrete injected columns;
Deep soil mixing columns</td></tr>
<tr><td>Deep foundations:
In-situ compacted piles;
CFA piles;
Driven piles</td></tr>
<tr><td>Geosynthetics:
Geotexitiles/Geogrids;
Geocells</td></tr>
</table>

Our interviews with district bridge engineers revealed the following about the preparation of soil foundations:

1. It is critical to perform a thorough subsurface exploration. The importance of the foundation exploration phases cannot be stressed enough. Responsible geotechnical personnel must be assigned this task.
2. Several ground improvement methods are implemented to provide an adequate foundation for new bridges. Highly compressible soils are made suitable by preloading the foundation soils and through excavation and replacement. Some STAs (e.g., Iowa, Texas) have adopted guidelines on foundation soils treatment. However, KYTC has not published a manual that designers and constructors can use to understand and execute different ground improvement methods for various field situations.
3. The process of preloading and precompressing the foundation soils typically requires a significant time commitment. Many districts reported that they are not willing to accommodate the preloading and/or precompression periods since this process may delay construction and drive up initial construction costs.
4. If the predictive models indicate that a constructed bridge's approach has been severely affected by foundations soils, engineers have two options. The first is to reduce the loads applied to the foundation; the other method is to improve the properties of the foundation soil through chemical grouting.

1.28 Embankment Backfill Material

Among the personnel we spoke with, the opinion was that high-quality granular engineered fill would influence the serviceability of embankments, particularly their slope stability, compression, consolidation, and bearing capacity. White et al. (2005) suggested that the embankment fill material should have the following properties:

- Easily compacted
- Not time-dependent
- Not sensitive to moisture
- Provide good drainage

- Resistant to erosion
- High shear resistance

Hoppe (1999) summarized embankment material specifications and lift thickness and percent compaction requirements adopted by various STAs (see Tables 5.3 and 5).

Table 0.3 Embankment material specifications (Hoppe, 1999)

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
CT	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 weight
KY		<10	Granular
LA			Granular
ME	Different	<20	Granular borrow
MA	Different	<10	Gravel borrow type B, M1.03.0
MI	Different	<7	Only top 0.9 m (3 ft) are different (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 conventional
TX	Same		
VT	Same		Granular
VA	Same		Pervious backfill
WA			Gravel borrow
WI	Different	<15	Granular
WY	Different		Fabric reinforced

Table 0.4 Lift thickness and percent compaction requirements (Hoppe, 1999)

State	Lift Thickness, mm(inch)	% Compaction	Miscellaneous
AL	203(8)	95	
AZ	203(8)	100	
CA	203(8)	95	For top 0.76 m (2.5 ft)
CT	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	
IO	203(8)	None	One roller pass per inch thickness
KS	203(8)	90	
KY	152(6)	95	Compacted lift indicated; Moisture = +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	
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	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

Forty-nine percent of STAs have more rigorous material specifications for an approach fill than for a regular highway embankment fill. In general, 95 percent of the standard proctor test compaction condition is specified for the compaction of approach fill. Since embankments must provide a smooth transition between the roadway and the bridge, the KYTC Structural Design Manual contains design and construction standards for both material 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 typically used except when special construction methods are specified when granular embankment materials are erodible or unstable.

In addition to the selection of embankment backfill material, most of the engineers we spoke with cited that precompression techniques used during embankment construction were a key method to minimize the potential of settlement and lateral movement development of the approach embankments. The precompression in embankment construction is a process in which the weight of the embankment is treated as a load that induces the consolidation settlement. It should be completed prior to the beginning of actual pavement or roadway construction (Puppala, 2009). Similar to the precompression method for foundation soils, this embankment method causes delays in most of the cases (sometimes up to a year). Designers and engineers must develop schedules that account for this step, which is necessary to let embankments settle before roadway construction begins (Cotton et al., 1987).

Another effective strategy to mitigate or eliminate excessive approach settlement is through the use of flowable fills. *Flowable fill* goes by other names, such as unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement, and soil-cement slurry (Du et al., 2006). Flowable fill is a low-strength mixing concrete used as a backfill behind abutment walls 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 can fill voids without requiring compaction, thus making the embankment as a whole uncompressible. The low-strength mixing concrete has been used by several KYTC districts and has performed well at preventing erosion of the backfill and enhanced the constructability of the fill behind the walls and its surrounding areas. Another advantage of this method that is can be executed quickly (Snethen & Benson, 1998). It is most appropriate for bridge projects with compressed schedules. The interviewees also observed that this method can be quite expensive. In certain field and construction scenarios, the use of this practice would drive construction costs higher. However, the benefit of reduced approach settlement offsets increased construction cost. Although flowable fill is widely used in Kentucky, no material requirements have been specified by KYTC. Districts rely on their past experience to implement their use. Colorado's DOT provides exact specifications on the material requirements for flowable fill. It stipulates the maximum lift thickness for flowable fill material is 3 feet. The placement of additional layers is not permitted until the flowable fill has lost enough moisture that it can be walked on without producing an indentation greater than 2 inches. Additionally, Colorado DOT specifies that flowable fill does not require any vibration because it may stiffen the fill by allowing accelerated setting in the field. The material requirements for flowable fill set by Colorado DOT is shown in Table 5.5. This could be used as a reference to develop guidelines for Kentucky. In Iowa, the flowable fill has been frequently used as a placement under the existing bridges. Smadi (2001) suggested the use of a flowable mortar has 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.

Table 0.5 Material requirements for flowable fill by Colorado DOT

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

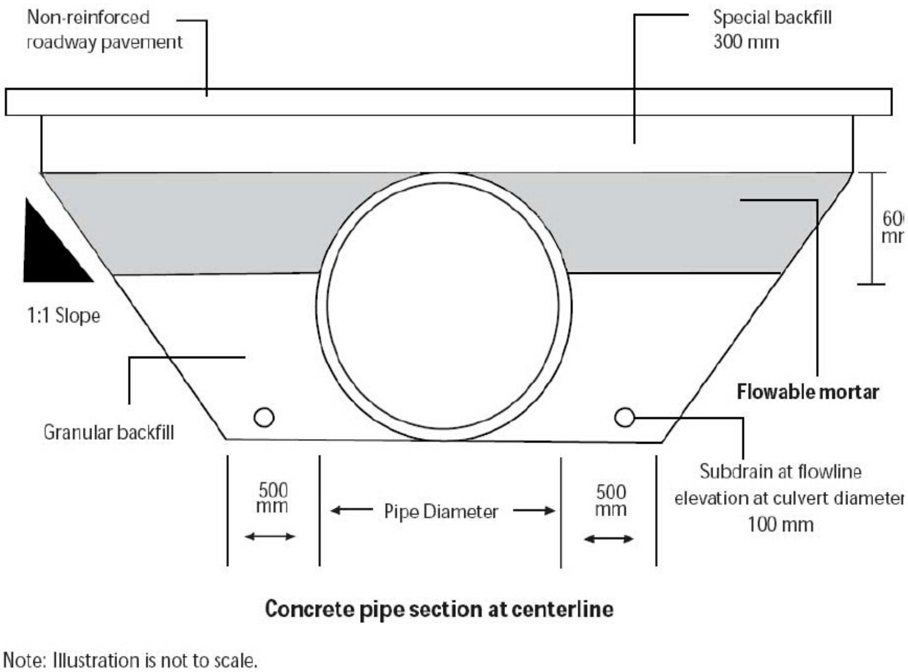


Figure 0.1 The flowable mortar used under a roadway pavement (Smadi, 2001)

When predictive models indicate that the approach settlement on a new bridge will be severe, a combination of backfill selection, precompression technique, and flowable fills can be used to eliminate excessive settlement induced by the embankment. If the amount of approach settlement predicted for an existing bridge is severe, flowable fill is also an effective way of solving the excessive approach settlement. It has been used effectively in the past by a number of KYTC districts. A manual on flowable fill design and construction is being developed by KYTC to guide the employment of flowable fill.

1.29 Approach Slab

The use of approach slabs is one of the most popular techniques to mitigate approach settlement. 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 voids beneath the approach slab form when approach settlement occurs. If the slab is not designed with enough reinforcement to support the unsupported span length, it may lead to cracking or complete failures (Dupont & Allen, 2002).

Surveying approximately 131 bridges in Texas, James et al. (1991) found 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 approach slabs with asphalt overlays tended to increase surface roughness. STAs specify that the use of approach slabs is only an option, not a requirement. Although approach slabs are used widely, some agencies (e.g., Kentucky, Maryland) argue that the use of approach slabs does not minimize the ultimate magnitude of settlement, and therefore does not warrant the additional construction costs. Although the use of approach slabs adds significant expense to construction, the analysis in Chapter 4 indicates that the use of approach slabs is a practical alternative in certain field and construction scenarios where the use of such practice justifies the higher costs.

Results from the Chi-square tests and the effective ratio demonstrates that the use of an approach slab can alleviate bumps caused by differential settlement. However, this is not to suggest that approach slabs can entirely eliminate bumps caused by differential settlement, or that approach slabs should be used for all bridges. Given that STAs have the responsibility of repairing differential settlement, the cost of methods to eliminate or minimize this problem is a significant consideration. STAs have developed many solutions to this problem from design, construction, and maintenance perspectives, however, the total cost of an approach slab and its life-cycle maintenance must not exceed the total cost of a flexible approach and its life-cycle maintenance. A new approach slab typically has a design life exceeding 20 years and costs between $5,000 and $10,000 (Dupont & Allen, 2002), which is much more expensive than a flexible approach. No statistical evidence has indicated 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 — which is used to taper the gradient change in order to achieve a smooth transition—cannot fix an improper approach slab, the slab must be replaced. Dupont and Allen (2002) concluded that the replacement cost of an approach slab may exceed $10,000.

To determine why approach slabs are used so infrequently in Kentucky, we asked KYTC bridge engineers and maintenance personnel. Their opinions are summarized below:

- The use of approach slabs is at the discretion of the project manager.
- Approach slab use varies significantly among districts. Districts 3 and 5 have used approach slabs as a preventative technique to minimize deferential settlement, while Districts 5, 11, and 12 lag behind. Other than approach slabs, sleep slabs are usually placed underneath and transverse to approach slabs to disperse the load transmitted to the embankment. Interviewees in District 3 commented positively on the performance of approach slabs. In District 5, the personnel we spoke with indicated that approach slabs were used for most bridges 20 years ago, but that no improvements in performance had been noted. Consequently, the district abandoned the use of approach slabs due to their high cost.
- The performance of the approach slabs hinges on a number of factors, including approach slab dimensions, steel reinforcement, whether a sleeper slab is used, and the type of connection between the approach slab and bridge. The mechanism that affects the performance of approach slabs is complex, and KYTC has no manuals that specify some design or construction issues, such as joint, length, vertical place, reinforcement, etc.
- Most districts cited high construction cost as the most significant consideration that influences decisions over whether to use 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 (e.g., embankment fill, compaction, drainage).
- No maintenance record from Kentucky or other states has conclusively demonstrated that life-cycle maintenance costs for approach slabs are lower than for flexible approaches.

1.30 Abutments

There are many possible abutment designs, which have been tried out on bridges throughout the United States. However, there is no consensus among experts over which type of abutment is best suited to minimize or eliminate the bump caused by differential settlement. There are two kinds of abutments most often used by STAs — non-integral and integral. Non-integral (or conventional) abutments have bearing connections and expansion joints to afford the superstructures with a certain amount of lateral movement between the abutment and the bridge deck (Figure 5.2; Wahls, 1990). Integral bridge abutments (Figure 5.3) were developed to eliminate the use of bearing plates and to reduce potential maintenance problems (Horvath, 2000). Integral abutments are stub abutments connected tightly to the bridge superstructure without any expansion joints (Wahls, 1990). Non-integral abutments and integral abutments are commonly employed by many STAs, including Kentucky.

In Chapter 3, we classified abutment types into three categories — closed, spill-through, and perched. Generally, closed and spill-through abutments are non-integral abutments, while perched abutments can be either non-integral or integral abutments. Our data analysis did not reveal a significant association between abutment type and the magnitude of approach settlement. However, several studies have shown that the type of bridge abutment figures importantly in approach settlement. Pierce et al. (2001) concluded that bridge approaches with integral abutments tend to have smoother surfaces than bridges with non-integral abutments. Another study (Wahls, 1990) reported a problem related to cracking and bulking at the approach pavement due to lateral cyclic movement of the abutment, which stems from thermal-movement-induced stresses at the bridge decks. Lateral movement has proven to be the most significant problem for integral abutments. The bridge superstructure expands or contracts due to seasonal air temperature fluctuations owing to concrete thermal strain properties.

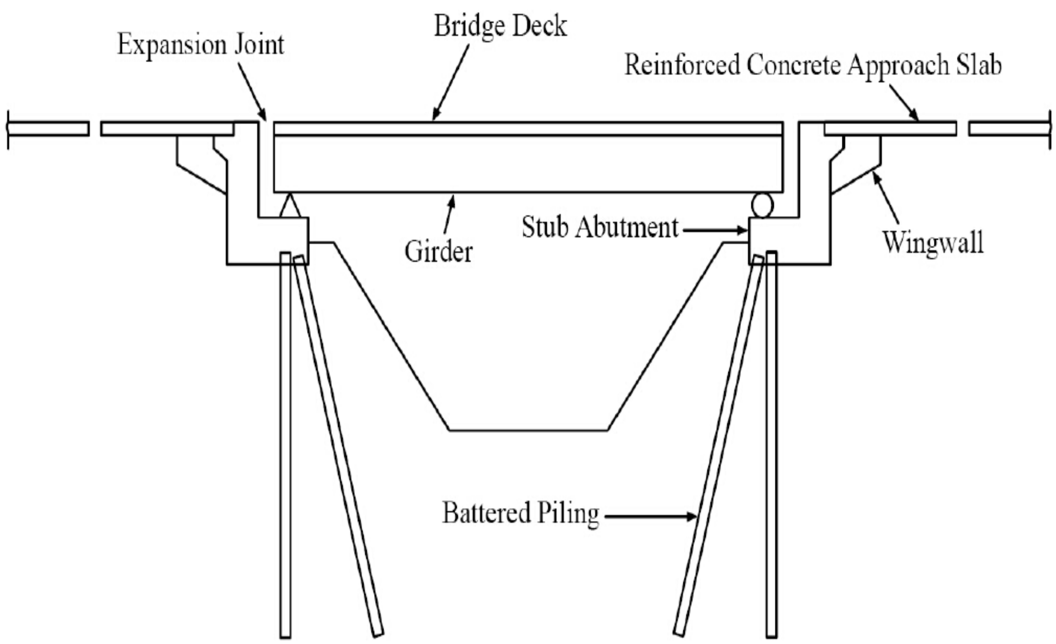


Figure 0.2 Simplified cross section of non-integral abutment bridge (Greimann et al., 1987; White et al., 2005)

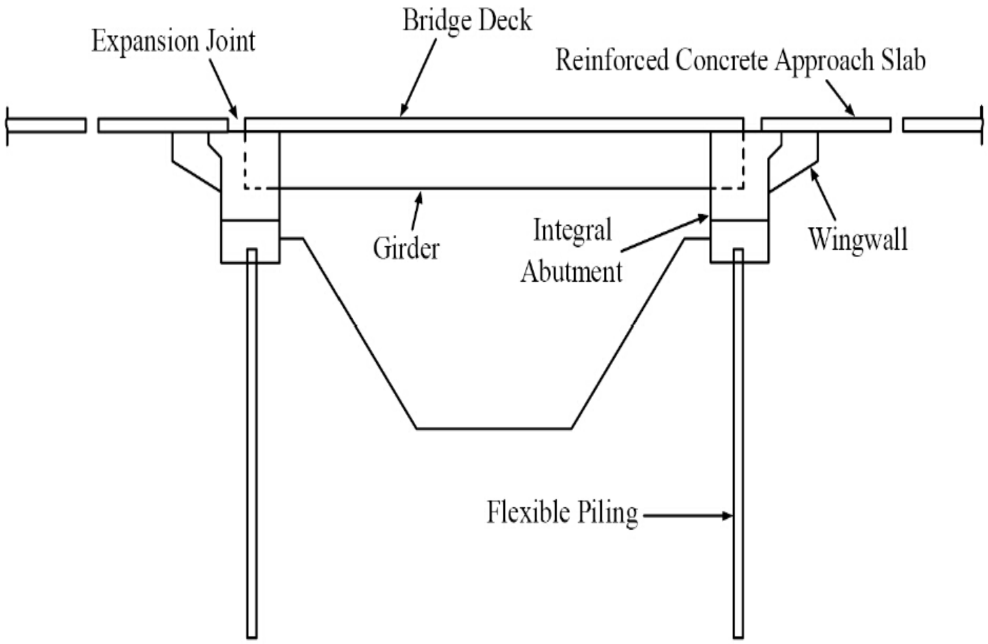


Figure 0.3 Simplified cross section of integral abutment bridge (Greimann et al., 1987; White et al., 2005)

KYTC district personnel commented that abutments supported by pile bent (perched) are generally more economical than spill-through (open column) abutments on spread footings. Pile bent abutments are typically the first choice of engineers when they decide between the two types of abutments. 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, KYTC's structural design manual suggests that integral abutments are preferable to non-integral abutments, and that backwalls and expansion joints should be constructed for pile bent abutments. Different abutments have different requirements for embankment backfill in design and construction in Kentucky.

1.31 Drainage

Approach drainage is another key influence on differential settlement. Water that collects on the road surface and bridge pavement can flow into the underlying fill materials if there are ineffective seals at the joints or cracks that separate the bridge approach from the abutment. When water infiltrates these joints or cracks, significant damage to the bridge approach may result. On bridges without approach slabs, the infiltrated water will immediately cause settlement, producing a bump in the road. Even if a bridge has an approach slab, erosion can amplify the development of voids caused by compression of backfill and lateral deformations (Dupont & Allen, 2002). As such, the design of the bridge approaches must integrate efficient drainage systems (Abu-Hejleh et al., 2006). Dupont and Allen (2002) also pointed out that the construction costs that include a reliable drainage system are not high when compared to the expensive maintenance costs that could otherwise result from ineffective drainage. Therefore, the significance of designing bridge approaches with effective seals and good drainage is critical.

In Chapter 4, we could not include drainage in the predictive model as either a quantitative or qualitative variable because it is challenging to evaluate the performance of a drainage plan for a bridge based on limited data. Also, it is too simple to consider drainage as a binary variable (i.e., treating a drainage design as present or absent) because most bridges have some type of drainage system in place. This section summarizes the current practices used by KYTC and STAs.

Generally, a bridge approach must include both surface and subsurface drainage outlets. Briaud et al.'s (1997) surface drainage design introduced a way of designing wingwalls curb-to-curb so they direct the water away from bridge joints (Figure 5.4). For subsurface drainage design, methods that have been considered by most STAs are 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. Layers of granular materials should be arranged sequentially and have the appropriate thickness to prevent water from exiting the wall face, which causes erosion. Outlets should be installed to wick the discharge of seepage away from the reinforced soil structure. Abu-Hejleh et al. suggested a drainage system that uses mechanically stabilized earth (MSE) walls (Figure 5.5). Nassif (2002) introduced a subsurface drainage design that involves constructing a layer of filter material before placement of the backfill. After this, perforated pipes are installed at the bottom to discharge the collected water (Figure 5.6).

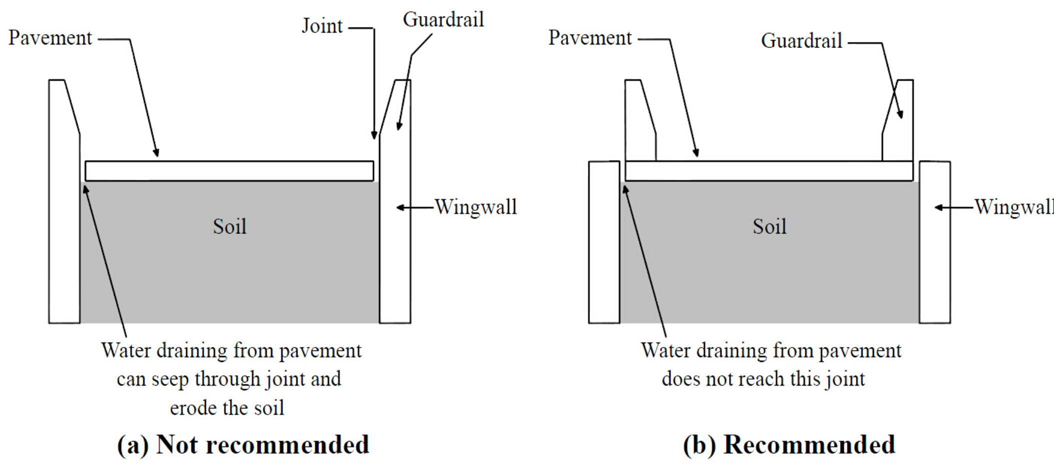


Figure 0.4 Approach slab joint details at pavement edge (Briaud et al., 1997)

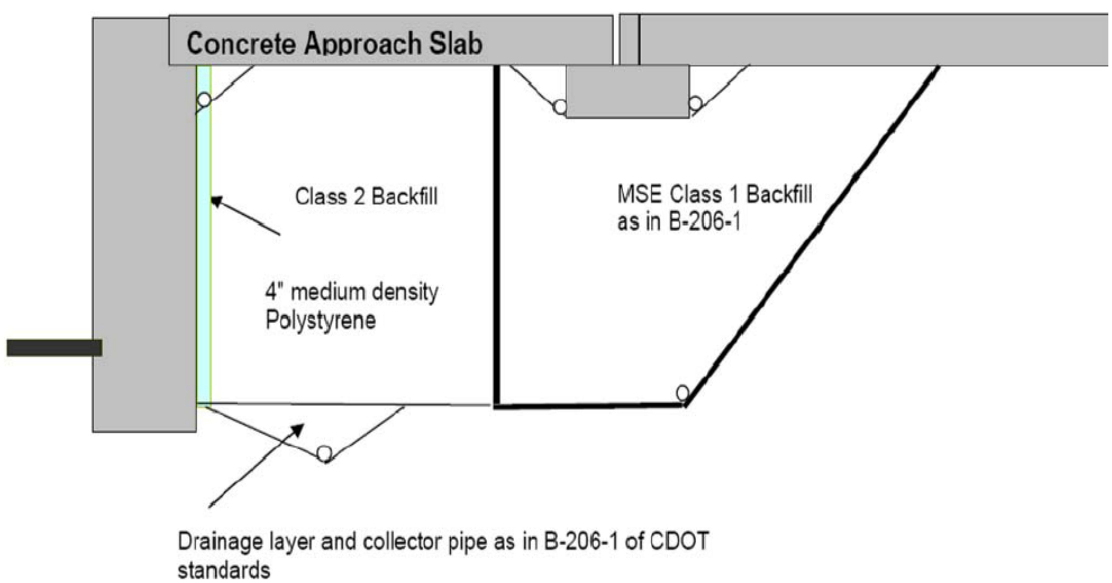


Figure 0.5 Mechanically stabilized earth (MSE) walls system under sleeper slab (Abu-Hejleh et al., 2006)

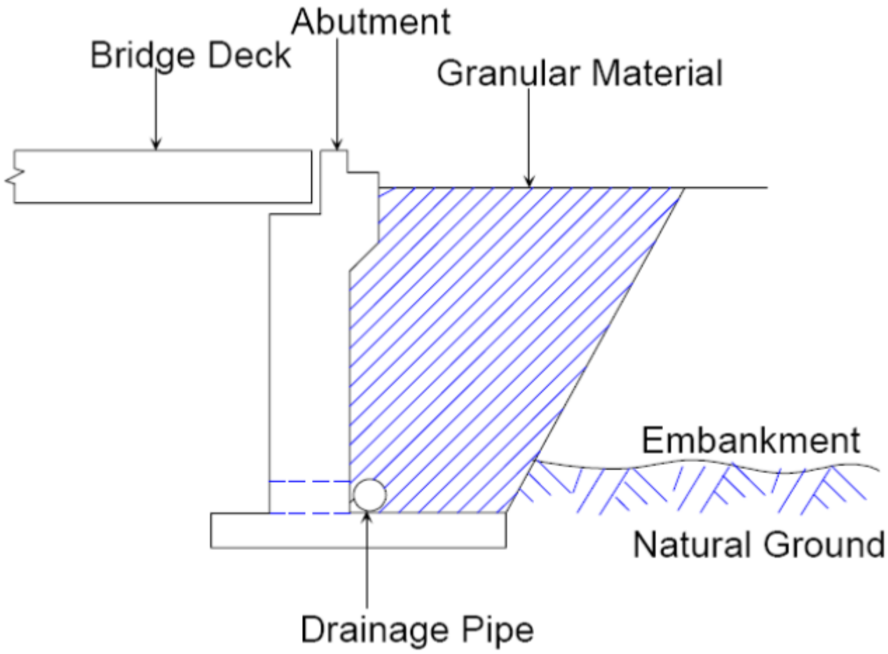


Figure 0.6 Drainage layer of granular material and collector pipe (Nassif, 2002)

Our survey of the literature indicates that the following measures can help improve drainage conditions:

- Use of porous backfill material
- Flatten side slopes
- Use of a curb-to-curb design to control erosion and drain 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
- Installation of a large-diameter surface drain and gutter system in the shoulder of the approach slab (if the bridge has an approach slab)
- Use of a geo-composite vertical drainage system around embankments
- Installation of plastic drainpipes and weep holes in the abutments
- Emplacement of a thick layer of tire chips as an elastic zone behind the abutment with a high capacity of drainage
- Installation 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

According to White et al. (2005), three main drainage system variations have been adopted across the United States: (1) porous backfill around a perforated drain pipe, (2) geotextiles wrapped around porous fill, and (3) vertical geo-composite drainage systems (Figures 5.7 to 5.10). Fourteen out of 16 states use a combination of two or more of these methods to increase drainage efficiency (Table 5.6).

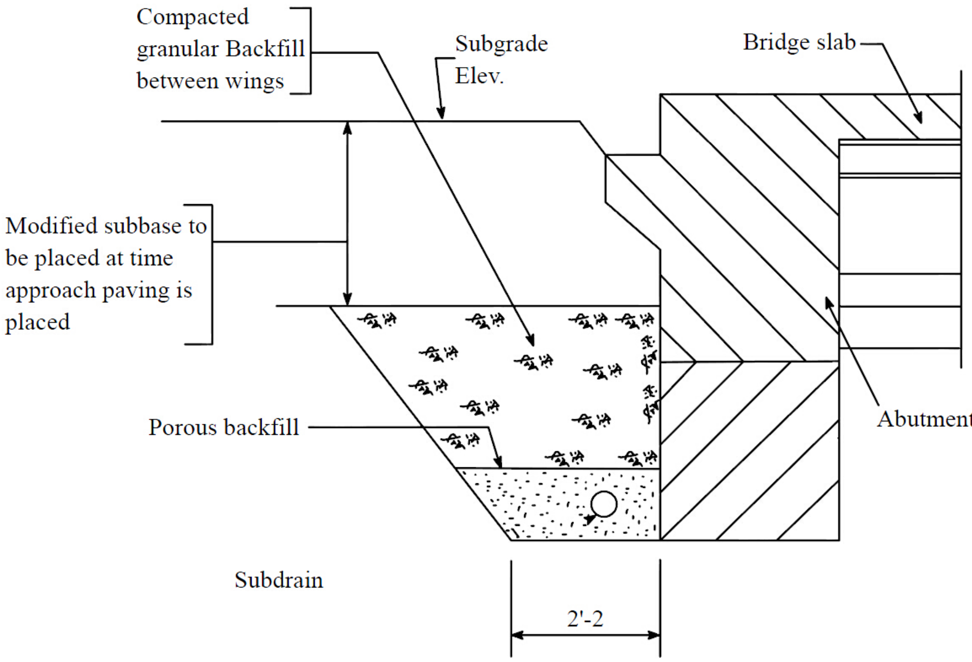


Figure 0.7 Schematic of porous fill surrounding subdrain (Iowa DOT, 2005)

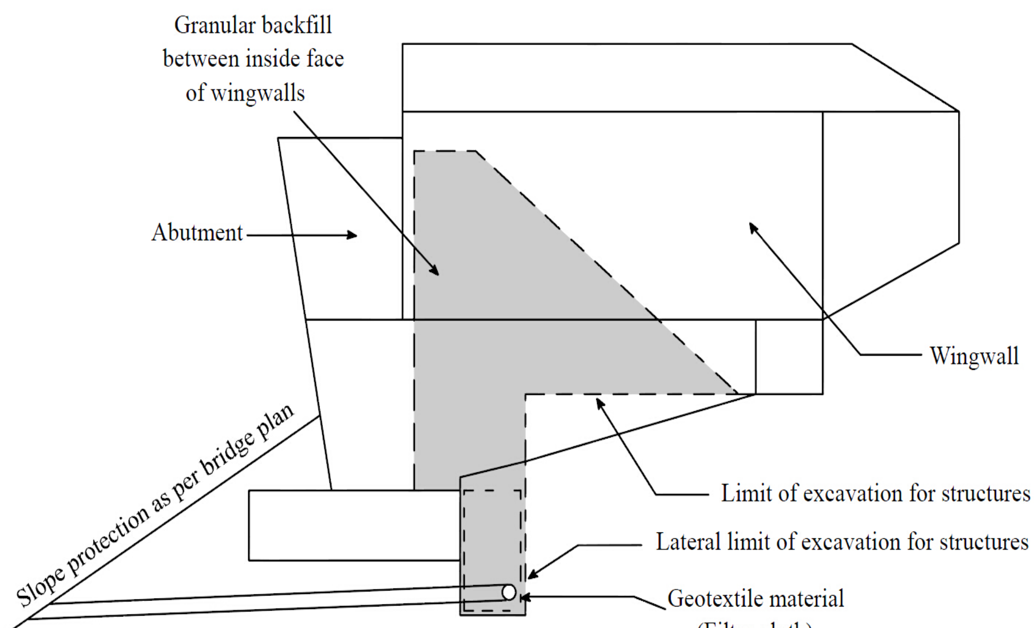


Figure 0.8 Schematic of granular backfill wrapped with geotextile filter material (Wisconsin DOT, 2003)

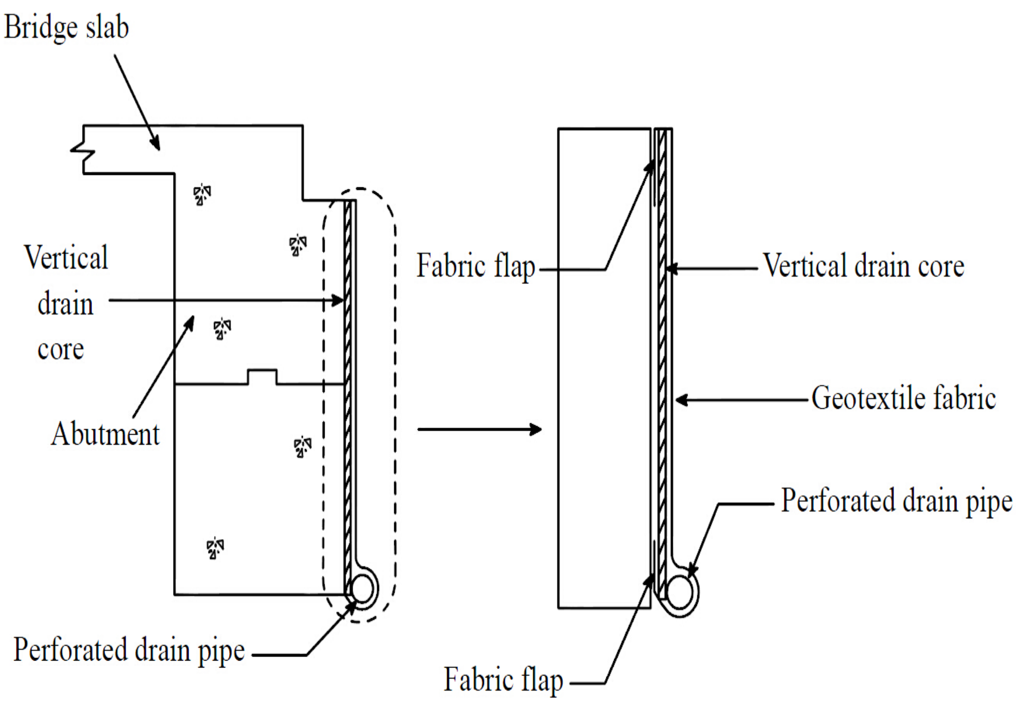


Figure 0.9 Schematic of geocomposite vertical drain wrapped with filter fabric (Missouri DOT, 2005)

Table 0.6 Drainage method used by various states (White et al., 2005)

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

Most of the engineers we spoke with mentioned the use of porous backfill behind the abutment as an effective strategy to enhance drainage capacity and reduce erosion. In Kentucky, AASHTO specifications guide the selection of material type and use. Several districts occasionally install drainage systems of granular backfill wrapped with geotextile. To date, KYTC has issued no special provisions related to the design of bridge approach drainage.

CONCLUSIONS AND RECOMMENDATIONS

1.32 Summary

Ideally, a bridge approach provides a smooth and safe transition for vehicles passing from roadway pavement onto a bridge structure. However, differential settlement between the roadway pavement, which rests on embankment fill, and the bridge abutment, which is constructed on a more rigid foundation, often creates a bump in the roadway. In the United States, highway agencies dedicate significant portions of their maintenance budgets to minimize or eliminate the bump problems caused by differential settlement. Maintenance work leads to traffic delays and creates unsafe riding conditions for motorists along heavily trafficked corridors. Predicting bridge approach settlement can play an important role in selecting proper design, construction, and maintenance techniques and/or measures. Bridge designers can use the predictive model described in this report to estimate the magnitude of approach settlement based on variables such as foundation, approach, embankment, and other bridge characteristics. With the information generated by the predictive model, designers can then apply techniques and/or measures in the preliminary phase to prevent or minimize the settlement problems that may occur in the future. The predictive model also has utility for bridge maintenance engineers, who can use it to evaluate the performance of an existing bridge's approach based on factors such as how the bridge is used, approach year, location, Average Daily Traffic (ADT), and approach type. Based on the predictive model's findings, engineers can implement maintenance activities with the highest likelihood of correcting distressed bridge approaches.

This study's principal findings were derived from statistical analyses, which identified the factors that significantly influenced the formation of the approach settlement and further, developed a predictive model that can be used to estimate approach settlement. The predictive model relies on a combination of quantitative and qualitative data inputs. To develop the model, the research team obtained two bridge samples through different selection methods. Sample 1 included 87 bridges, which were identified with the assistance of bridge engineers in KYTC's district offices. Sample 2 was a randomly generated sample of 600 bridges from an internal network server "Pontis," which is used to store the inspection history of most of the bridge approaches in Kentucky.

This study differs from previous ones in terms of its methodological approach. Earlier studies frequently relied on a micro method to observe and assess the performance of bridge approaches. The macro method employed in this study leveraged numerous variables to develop the predictive model. Maintenance times, maintenance measures, and observed settlement were used to classify the magnitude of differential settlement as minimal, moderate, and severe. These categories correspond to approach performance rankings of good, fair, and poor, respectively. Researchers then identified 10 independent variables that may significantly contribute to the formation of approach settlement, which included count data and categorical (ordinal and nominal) variables. The model's response variable was ternary — minimal, moderate, or severe. Assigning an ordinal response was premised on the assumption that the levels of approach settlement have a natural ordering (low to high), but the distances between adjacent classifications are not consistent. Ordinal logistical analysis was used to perform the statistical modeling. If the ordinal logistic analysis violated this assumption, the less restrictive multinomial logistic method was chosen. A Chi-square test was used first to identify whether associations existed between each independent variable and approach settlement levels. Both methods of ordinal logistic regression and multinomial logistic regression were used to develop the comprehensive models. These models incorporated all the independent variables.

Two predictive models were developed to estimate the probability that a roadway–bridge transition will undergo minimal, moderate, or severe settlement. The models can be used to estimate the likelihood that a bridge would experience minimal, moderate, or severe settlement as a function of the covariates. Results are expressed in terms of odds ratios for severity choice, given bridge characteristics. Users can select one or two models to predict the magnitude of approach settlement for a new bridge or for an existing bridge.

The research team visited five KYTC districts to collect data on current practices that are used to alleviate bump problems caused by approach settlement. From these interviews, a catalog of techniques was developed relating to the design, construction, and maintenance used to ameliorate the effects of differential settlement. Bridge engineers can draw from this catalog to identify corrective measures that are most appropriate to reduce or to eliminate approach settlement of existing or planned bridges. These techniques focus on foundation soil, embankment backfill material, approach slab, abutments, and drainage. Chapter 5 summarizes the information collected on this topic.

1.33 Conclusions

Our predictive model will assist engineers in estimating the magnitude of approach settlement for a new or an existing bridge, given bridge characteristic variables such as approach, embankment, abutment, traffic volume, and foundation. Based on the findings, researchers have drawn the following conclusions:

1. It is imperative for KYTC to treat the approach system as a standalone design objective. Several states (e.g., Iowa, Texas, Wisconsin) have begun to develop design manuals on approach design. Interviews with KYTC personnel revealed that most issues related to approach design are the responsibility of the project manager. Maintenance techniques used to alleviate differential settlement vary greatly among districts.
2. The macro method described in this report, which relies on a combination of maintenance times, maintenance measures, and observed settlement has proven robust at classifying the magnitude of differential settlement. Observations of approach settlement are not required to evaluate the performance of approaches if a record of approach maintenance activities has been kept.
3. A legible, accurate, and accessible record keeping system of inspection and maintenance is an effective and straightforward tool for helping KYTC staff discover and manage bridge approaches when excessive approach settlement occurs.
4. For Sample 1, logistic regression demonstrated that approach age, transportation district, and foundation soil depth are the three most important factors influencing the formation of approach settlement. As the age of a bridge increases, the likelihood of it suffering from more severe levels of settlement decreases. District 1, District 10, and District 11 are the most proactive in their efforts to address differential settlement at bridge ends. The likelihood of an approach experiencing higher magnitudes of settlement decreases as the foundation soil depth of a bridge increases.
5. For Sample 2, logistic regression indicated that transportation district, approach age, ADT, and approach type are the four most important variables contributing to the development of approach settlement. The model demonstrated a positive correlation between bridge age and the severity of approach settlement, from which can be inferred that the magnitude of approach settlement increases as bridge age increases if all other independent variables are held constant. As ADT for an approach increases, the probability of settlement worsening increases. Additionally, flexible approaches are more prone to more severe approach settlement than rigid approaches.
6. There is a significant relationship between approach type and the magnitude of approach settlement. The use of approach slabs has been useful for mitigating bump problems, based on the locations where they have been installed in Kentucky. The use of approach slabs could enhance the performance of approaches as transitions between roadway and the bridge. However, the model did not indicate their effectiveness was significant because the effective ratio was slightly larger than 1.
7. The variation trends of the predicted probability of minimal settlement versus the statistically significant predictors met well with the logistic regression results for Sample 1. The probability of settlement being classified as minimal increases as an approach's age increases. Bridges in Districts 1, 10, and 11 are more likely to exhibit minimal settlement than bridges in other districts.

Additionally, the likelihood of the settlement being classified as minimal increases until the foundation soil depth approaches 25 feet. It then decreases as the soil depth increases.

8. The variation trends of the predicted probability of minimal settlement versus the statistically significant predictors met well with the logistic regression results for Sample 2. The magnitude of bridge approach settlement in Districts 1, 3, and 10 ten is more likely to be classified as minimal, compared to other districts. The likelihood of minimal settlement existing decreases as the age of the approach increases. Further, the probability of an approach exhibiting minimal settlement decreases as the ADT increases. Lastly, rigid approaches are more likely to have minimal settlement than flexible approaches.
9. The techniques KYTC uses most often to improve highly compressible foundation soils are preloading the foundation soils or excavation and replacement. Two easy and reliable alternatives are proposed for when the foundation soils are not adequate. The first is to reduce the loads applied to the foundation. The second method is to improve the properties of the foundation soil with chemical grouting. KYTC has not developed a manual to guide designers and engineers in carrying out different ground improvement methods under various field conditions.
10. Many districts reported that they are not willing to accommodate the preloading and/or precompression periods since this process may delay construction and drive up initial construction costs.
11. Most bridge engineers reported that the precompression technique for embankment construction has been successful. Another effective method to reduce excessive approach settlement is with the use of flowable fills.
12. The use of approach slabs varies significantly among districts. KYTC lacks manuals that address approach slabs or that clarify design and/or construction issues. Most districts cited high construction costs as the most significant factor influencing the widespread use of approach slabs. Maintenance records from Kentucky and other states have not proven that life-cycle maintenance costs for approach slabs are lower than for flexible approaches.
13. Abutments supported on pile bent (perched) are generally more economical than spill-through (open column) abutments on spread footings. KYTC recommends using integral abutments rather than non-integral abutments.
14. The use of porous backfill behind the abutment enhances drainage capacity and reduces erosion around the abutment. Several districts occasionally use granular backfill wrapped with geotextile as drainage systems. KYTC has no special provisions related to the design of bridge approach drainage.

1.34 Recommendations for Future Research

This research contributes to the existing body of construction engineering knowledge. There are numerous directions in which to extend this research with topics in structural engineering, transportation engineering, and statistics being at the forefront. In view of the present study, here are the following recommendations for additional research:

1. Refine the predictive models by expanding the sample bridge population. Consultations with bridge engineers could be used to identify candidate sites for inclusion. This will prove beneficial and generate more robust statistical findings because in a small sample size, logistic regression may produce an unstable model.
2. Additional variables could be added to the predictive models to gauge their influence on differential settlement. Possible variables include temperature cycle, connection between the approach and the bridge, compressibility characteristics of embankment, and drainage design of approaches.
3. Conduct an in-depth study of the effects drainage has on the formation of approach settlement. There is a consensus among engineers that drainage plays a significant role in the development of differential settlements at bridge ends.

4. The models developed as part of this research are based on the judgment of local bridge engineers and KYTC inspection records. Field visits should be conducted to validate the predictive models. Approach settlement should be measured and compared to modeling results. The creation of a database that stores observed settlement for bridges throughout Kentucky could facilitate the development of new statistical methods to predict approach settlement magnitude.
5. The team built models using bridge data only from Kentucky. Bridges from other states should be included to develop a more comprehensive understanding of differential settlement and its impacts throughout the United States.
6. Explore the potential of using abutment construction characteristics and amount of backfill as inputs for a new model. Interviews with construction engineers are recommended as well as visits to observe abutment construction and the emplacement of backfill.
7. Some information on foundation soil used to develop the models was not very accurate. Field tests should be carried out to investigate the foundation soils if this information is not obtainable 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.

2	Ghorbanpoor, Al; Koutnik, Therese Ellen; Helwany, Sam; Wisconsin DOT; 2007	Evaluation of bridge approach settlement mitigation methods	• 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 less than 5 to 7 feet of fill were insignificant over five years compared with the movements of 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

3	White et al; Iowa DOT; 2007	"Underlying" Causes for Settlement of Bridge Approach Pavement Systems	• 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 cover, severe faulting in the approach pavement, and loss of backfill around subdrain elements • 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
4	Hoppe; Virginia DOT; 2006	Field Measurements on Skewed Semi-Integral Bridge with Elastic Inclusion: Instrumentation Report	• Data obtained by monitoring earth pressure cells, load cells, and strain gages would be useful for future endeavors

5	Abu-Hejleh et al; Colorado DOT; 2006	Flowfill and MSE bridge approaches: Performance, Cost and Recommendations for Improvements	• 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 to alleviate the approach bridge bump problem • The high quality backfill materials should be placed under the sleeper slab • The length of the approach slab 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 Mexico DOT; 2006	Settlement Issues – Bridge Approach Slabs	• MSE walls have fewer problems with approach slab settlement issues than other types of bridge abutment systems

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

10	David White, Sri Sritharan; Iowa DOT; 2005	Identification of the Best Practices for Design, Construction, and Repair of Bridge Approaches	• 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 of the inspected bridges. Several abutment subdrains were observed to be either blocked with soil, dry, indicating no water flow, or 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
11	Mekkawy et al.; Iowa DOT; 2005	Simple Design Alternatives to Improve Drainage and Reduce Erosion at Bridge Abutments	• Three alternatives are recommended to improve drainage and alleviate erosion: 1) use geocomposite drain with granular backfill reinforcement, 2) use tire chips behind the bridge abutment, and 3) use porous backfill material

12	M. Schmitz; Kansas DOT; 2004	Use of Controlled Low-Strength Material as Abutment Backfill	• 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 settlement of the embankment itself. This may lead to significant differential settlement between the approaches and bridges, which are 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.
13	Ronaldo Luna; MoDOT; 2004	Evaluation of Bridge Approach Slabs Performance and Design	• 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 bridge designers • Modern numerical method is used 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

14	Seo et al.; TxDOT; 2003	The bump at the end of the bridge: an Investigation	• 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 occurring in the first 6 m for a uniform load case • 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
15	Arsoy et al.; VTRC/VDOT; 2002	Performance of Piles Supporting Integral Bridges	• Steel H-piles oriented in the weak-axis bending area is a good choice for support integral abutment bridges • Pipe Piles will cause higher stress in the abutments than steel H-piles • Concrete piles are not a suitable choice. Tension cracks due to cyclic lateral load can reduce their vertical load capacity
16	Nassif; NJDOT; 2002	Finite element modeling of bridge approach, transition slabs using ABAQUS, and identifying the probable cause of cracking	• The number one reason for the bump is the settlement of the embankment fill followed by the loss of fill by erosion • The settlement at the bridge approach is worse when the embankment is high and the fill is clay • The settlement at the bridge approach is lessened when an approach slab is used and the abutment fill is cement stabilized

17	Dupont and Allen; Kentucky Transportation Center (KTC); 2002	Movements and settlements of highway bridge approaches	• Lowered approach slabs with asphalt overlays • Require settlement periods and/or surcharges prior to final construction • Design Maintenance plans concurrent to construction plans • Implement specifications for select fill adjacent to abutments • Improve drainage designs on and around approached • Require bridge approach warranties • Reduce the side slope of embankments • Improve approach slab design
18	Marquart, M.; NDDOT; 2002	Fabric Reinforced Backfill under Approach Slabs	• 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 also be caused by snowplows in the winter • 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

19	Ha and Briaud; TxDOT; 2002	Investigation of settlement at bridge approach slab expansion joint: survey and site investigations	• The number one reason for the bump is the settlement of the embankment fill followed by the loss of fill by erosion • The soil near the abutment was weaker and wetter than the soil away from the abutment • The soil near the abutment had a relatively high Plasticity Index (PI) for an embankment fill • 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
20	Pierce, Charles E; SCDOT; 2001	Investigation into improvement of bridge approaches in South Carolina	• Conducted visual inspection and quantitative assessment of bridge approach slabs located at 25 bridges in 11 counties across South Carolina, and assessed the performance level of bridge approach slabs and determine the rideability of the road-to-bridge transition
21	Parsons; Kansas DOT; 2001	Compaction and settlement of existing embankments	• Eight embankments constructed between 1994 and 2000 were selected for undisturbed field sampling. Two borings were drilled in each embankment and shelby tube samples were collected for testing at regular intervals. Samples of the cuttings were also collected for testing. A telephone survey of all state DOTs was conducted to assess current practice with regard to specifications for compaction of fills.

22	Abu-Hejleh et al.; Colorado DOT; 2001	Results and Recommendations of Forensic Investigation of Three Full-Scale GRS Abutment and Piers in Denver, Colorado	• GRS abutment and piers are practical alternatives used in bridge support • GRS should not be used in a scour situation • GRS piers are suitable for remote locations, since it can be constructed or repaired by using small construction equipment within a few days
23	Hoppe; VTRC/VDOT; 1999	Guidelines for the use, design, and construction of bridge approach slabs	• Full-width approach slabs are used. It reduces erosion of the approach fill • Placing approach slabs below the road surface facilitates resurfacing operations • Drainage system between the top of the approach slab and the surface of the road should be provided • Pre-cambering may be employed to compensate differential settlement at bridge approaches resulting from differing foundations beneath the bridge and theroadway
24	Sankar; Louisiana TRC; 1999	Assessment of mitigating embankment settlement with pile-supported approach slabs	• Identified the factors that contribute to total approach settlement in pile supported approach slabs in southeastern Louisiana. The main factor affecting slab settlement is downdrag, or negative skin friction, load imposed on the pile due to the weight of the roadway embankment.

25	Reid et al.; SDDOT; 1999	Use of fabric reinforced soil wall for integral abutment bridge end treatment and investigate the effectiveness of present design	• Voids reduced by using the rubber tire chips behind the integral abutment • Cyclic movements do not affect the voids
26	Snethen et al.; Ohio DOT; 1998	Construction of CLSM approach embankment to minimize the bump at the end of the bridge	• The use of Control Low-Strength Material (CLSM) as an approach embankment fill material as a simple and cost effective method to reduce the potential for developing the bump at the end of the bridge
27	Hearn; Colorado DOT; 1997	Faulted pavements at bridge abutments	• Synthesis on faulted pavements at bridge abutments; Occurrence of pavements faults. Reported causes; Mitigation of pavement faults; Observed total settlements; Prediction of 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

29	Schaefer and Koch; SDDOT; 1992	Survey done to isolate and determine the mechanisms controlling backfill to reduce void development under bridge approaches	• Thermal induced movements of integral abutments are responsible for void development • No problem with the material used as a backfill • Voids are not developed due to erosion • Cracking is due to loss of support • Mud jacking does not affect the formation of voids • Non-integral abutment reduces the problem of voids • Maintenance cost increases by using integral abutments
30	Laguros and Zaman; OKDOT;1990	Evaluation of causes of excessive settlements of pavements behind bridge abutments and their remedies	• Settlement problem is due to the absence of drainage • Major portion of the settlement occurs within first twenty years • Skewed approaches have higher approach settlement than non-skewed approaches • Regression techniques were used to develop an empirical relationship between the approach 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
34	Hopkins, KyDOT; 1985	Long term movements of highway bridge approach embankments and pavements by surveying and observation of six bridge sites from 1966 to 1985	• Settlement of bridge approach foundations contributes significantly to settlements of approach pavements • Improper compaction, lateral movements, erosion of materials, and secondary compressions are the causes for long-term movement of bridge approaches
35	Greimann et al.; Iowa DOT; 1984	Deign of Piles for Integral Abutment Bridge	• The ultimate load capacity for frictional piles was not affected by lateral displacements of up to 4 in. for Hpiles and up to 2 in. for timber and concrete piles • The ultimate load capacity was considerably decreased if lateral displacements greater than 2 in. for end-bearing H- piles

36	DiMillion; WSDOT; 1982	Performance of Highway Bridge Abutments Supported by Spread Footing on Compacted Fill	• Spread footing on compacted fill supporting the bridge abutment is very reliable and inexpensive • The superstructure with a spread footing can withstand temperate settlement (1-3 in.) without distress
37	Hopkins; KyDOT; 1969	Preliminary survey done on the existing bridges to calculate settlement of highway bridge approaches and embankment foundations by using special experimental design and construction features at selected bridge sites	• Concrete bridge approaches are better than bituminous bridge approaches • Progressive failure or creep of the approach is a cause for the development of an approach fault • Erosion of soil from abutments contributes to development of defective bridges. • Traffic is not a cause for the settlement • Backfilling around abutments with a granular material did not arrest the development of faulted approaches • Settlement of the approach foundation and embankment contributes significantly to settlement of bridge approaches and approach pavements • Replacing the soft compressible material with rock or compacted 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					
Bridge 2					

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 tim.taylor@uky.edu. We would appreciate your response by April 1st, 2014

Appendix C: Detailed Data Information of Sample One

Bridge_ID	District	Length	Width	AppAge	ADT	AbuType	AppType	EmbHeight	FSoilDepth	Consistency	Severity
061B00099N	11	136	24	4	2460	3	1	7	21	2	3
056B00495N	5	281.5	66	5	58200	3	1	32	15	2	2
056B00489N	5	356.2	30	5	80000	2	1	29	8	2	2
056B00492N	5	159.7	24	5	58200	1	1	17	0	4	2
056B00494N	5	308	30	5	58200	3	1	24	17	3	2
049B00072N	6	889	24	6	12200	3	2	22	12	3	3
118B00123N	11	175.9	40	6	4010	3	2	18	19	2	3
115B00065N	4	683	40	8	706	3	2	18	13	3	3

056B00488N	5	353	60	8	17400	2	1	18	0	4	2
041B00062N	6	255.6	18	8	296	3	1	5	14	2	2
041B00065N	6	242.5	28	8	393	3	1	18	8	2	3
039B00048N	6	286.5	24	8	29400	3	1	21	14	2	3
041B00069N	6	450	30	8	2440	3	1	33	7	2	3
041B00067N	6	236	24	8	484	3	1	4	21	2	3
041B00064N	6	234.7	24	8	393	2	1	3	2	2	3
076B00111N	7	272	20	8	1910	3	1	11	8	2	2
105B00144R	7	482	60	8	17600	1	2	22	0	4	3
105B00145R	7	172	16	8	17600	3	1	6	7	3	3
013B00082R	10	437	42	8	2290	3	1	19	21	2	1
013B00083R	10	567	32	8	3615	3	1	16	32	3	2
041B00061N	6	257	18	9	565	3	1	18	11	1	2
079B00146N	1	296.9	24	11	2240	3	2	18	11	3	2
041B00058N	6	382	30	11	6110	1	2	42	0	4	3

084B00051N	7	177	34	11	631	3	1	8	19	3	2
096B00040N	6	200.1	56	12	11200	3	2	17	12	3	2
076B00105R	7	286.1	20	12	26950	3	2	5	12	2	3
045B00081N	9	272	16	12	5900	3	1	44	35	3	3
041B00052N	6	223	16	13	3480	3	2	0	7	3	1
076B00107N	7	252	30	13	15400	3	1	12	17	1	3
059B00104N	6	1474.1	22	14	13200	3	2	8	26	2	1
048B00181N	11	59.1	12	14	3580	1	1	4	0	4	2
073B00159L	1	205	40	15	4695	3	2	17	41	3	3
094B00041N	6	765.1	36	16	2800	1	1	11	0	4	3
070B00076N	1	57.1	14	17	3290	3	1	4	8	3	1
009B00068R	7	146	24	17	8600	1	1	7	0	4	2
048B00176N	11	329	12	17	2380	3	1	7	12	3	3
060B00076N	12	54	16	17	6710	1	1	6	0	4	3
056B00454R	5	402.7	42	18	13500	3	2	25	22	3	2

081B00067N	9	766.1	60	19	5110	3	2	76	52	3	2
097B00116N	10	284.1	40	20	4200	3	2	2	40	1	3
011B00055N	7	240	24	22	3370	3	2	21	10	3	3
061B00095N	11	517	48	22	8610	3	2	35	31	2	2
061B00091R	11	303	26	25	6650	2	1	14	22	3	3
039B00039N	6	387	24	26	3970	3	1	18	40	2	3
021B00054N	6	42.3	16	27	534	1	1	7	0	4	3
068B00101N	9	294	24	28	2900	3	1	22	42	2	3
021B00049N	6	265.1	24	31	5340	3	1	15	50	3	2
041B00038N	6	146	16	32	3980	3	1	21	6	3	2
048B00103N	11	302	24	39	637	3	1	42	22	2	1
048B00124N	11	130	40	39	6020	3	1	12	15	3	1
009B00052L	7	244.4	26	40	6150	1	1	9	0	4	2
048B00110N	11	369	44	40	5950	3	1	14	13	3	1
048B00118N	11	226	48	41	6020	2	1	12	19	3	2

048B00117N	11	300	48	41	6020	2	1	23	12	3	3
067B00081N	12	358.9	48	41	9190	3	1	16	22	2	3
111B00027R	1	151.9	42	42	9550	1	1	12	0	4	2
048B00114N	11	217	44	42	5950	2	1	21	21	3	2
048B00113N	11	208	44	42	5950	3	1	9	14	3	3
037B00053R	5	299.8	89	43	19050	3	1	12	15	2	2
052B00037N	5	139.2	19	45	1390	3	1	12	21	3	2
039B00010N	6	404.9	28	45	2720	3	1	12	11	1	2
022B00084L	9	227	40	46	6000	3	1	13	9	3	2
052B00051L	5	434.4	32	47	16950	3	1	42	18	2	2
056B00167R	5	274.5	52	48	34050	3	1	40	56	1	2
039B00017N	6	293	24	48	352	3	1	10	22	2	2
039B00030N	6	274	26	48	93	3	1	8	36	2	2
021B00038L	6	336	30	48	14600	3	1	30	14	2	3
039B00023R	6	154.9	40	48	13600	2	1	31	9	2	3

021B00037L	6	233.9	40	48	13600	3	1	28	60	3	3
022B00088L	9	144	44	48	7350	2	1	4	11	2	2
090B00019L	4	330.1	30	50	4950	3	1	26	13	1	2
050B00030L	4	194.9	24	51	18500	3	1	13	24	2	3
094B00001N	6	43	28	53	208	1	1	4	0	4	3
118B00059R	11	399	30	53	12700	3	1	15	29	2	1
118B00058R	11	347	30	53	12700	3	1	15	32	3	1
118B00054R	11	99	40	53	12700	3	1	13	15	1	1
041B00007N	6	254.8	32	54	6940	3	1	20	18	2	1
047B00036R	4	317.9	30	57	18200	2	1	0	44	2	2
108B00010N	5	407.4	28	57	4860	3	1	25	25	2	3
039B00022N	6	65	26	59	376	1	1	12	0	4	3
067B00027N	12	317.9	36	64	2910	3	1	15	13	3	3
049B00021N	6	265	26	66	14200	1	2	23	0	4	1
009B00002N	6	151.9	30	67	5170	1	1	8	0	4	1

118B000 40N	11	214. 9	38	72	315 0	1	1	12	0	4	1
048B000 12N	11	160	20	77	326 0	1	1	13	0	4	2
094B000 02N	6	65.9	20	79	244	1	1	8	0	4	2
039B000 06N	6	37	24	81	119 0	1	1	13	0	4	3

Appendix D: Detailed Data Information of Sample 2

Bridge_ID	Distr ict	Leng th	Wid th	App Age	ADT	AbuT ype	AppT ype	EmbHe ight	FSoilDe pth	Consist ency	Sever ity
065B000 24N	10	133	28	30	1106	3	1	0	36	2	1
077B000 84N	10	156	56	8	5798	1	1	5	50	2	2
004B000 28N	1	693	28	73	1631	3	1	13	26	2	1
004B000 61N	1	99	44	22	4155	3	1	13	50	2	1
016B000 50N	3	130	22	60	232	3	1	13	50	2	1
018B000 20N	1	99	23	82	1612	3	1	4	40	2	1
018B001 09N	1	115	22	58	768	3	1	8	39	2	1
018B001 15N	1	90	44	24	2070	3	1	3	50	2	1

018B001 16N	1	90	44	24	2070	3	1	3	50	2	1
020B000 24N	1	198	22	67	894	3	1	3	24	2	1
021B000 48N	6	211	30	31	8400	3	1	13	45	2	1
021B000 50N	6	361	30	30	6460	3	1	20	50	2	1
028B000 51N	1	157	20	53	120	3	1	12	36	2	1
036B000 96N	12	203	44	36	3070	3	1	13	50	2	1
038B000 11N	1	330	24	74	1040	3	1	2	32	2	1
038B000 65N	1	99	24	56	81	3	1	2	41	2	1
038B000 78N	1	238	40	30	2449	3	1	26	42	2	1
038B000 81N	1	71	44	27	2050	3	1	6	50	2	1
042B000 31N	1	84	24	52	341	3	1	9	40	2	1
042B001 94N	1	99	24	51	235	3	1	2	40	2	1
042B001 95N	1	99	24	51	235	3	1	4	40	2	1
053B000 33N	1	114	24	56	118	3	1	11	50	2	1
053B000 47N	1	175	24	74	994	3	1	3	33	2	1

063B00105N	11	34	22	15	41162	3	1	0	14	2	1
065B00026N	10	147	30	28	2350	3	1	8	50	2	1
067B00010N	12	237	44	45	8427	3	1	31	19	2	1
072B00020N	1	811	26	51	974	3	1	5	50	2	1
073B00010N	1	389	28	51	2300	3	1	27	50	2	1
073B00048N	1	114	28	55	2710	3	1	9	50	2	1
073B00049N	1	132	28	55	2774	3	1	10	50	2	1
073B00108N	1	430	28	40	1176	3	1	17	50	2	1
073B00113N	1	337	44	40	3119	3	1	10	20	2	1
073B00114L	1	458	39	40	18580	3	1	37	50	2	1
073B00115R	1	143	39	40	18580	3	1	6	50	2	1
073B00116L	1	197	40	40	15754	3	1	35	20	2	1
073B00119L	1	172	40	40	15754	3	1	45	15	2	1
073B00121N	1	260	88	40	12033	3	1	9	50	2	1
073B00153N	1	214	30	16	375	3	1	3	12	2	1

079B00013N	1	84	24	52	578	3	1	6	50	2	1
088B00042N	10	186	30	52	4690	3	1	20	13	2	1
097B00089N	10	646	32	42	9784	3	1	33	15	2	1
107B00040N	3	173	44	14	4165	3	1	27	41	2	1
111B00045N	1	317	28	41	1010	3	1	22	44	2	1
114B00053R	3	220	30	43	6322	3	1	0	20	2	1
004B00027N	1	300	24	73	1277	3	1	1	30	2	2
008B00051N	6	234	44	43	8207	3	1	18	50	2	2
008B00066N	6	305	54	30	68372	3	1	4	50	2	2
016B00016N	3	264	24	80	2630	3	1	12	50	2	2
019B00066N	6	93	82	25	9757	3	1	11	42	2	2
021B00039R	6	336	30	48	14600	3	1	4	10	2	2
021B00058N	6	275	32	9	917	3	1	22	50	2	2
022B00132N	9	63	28	31	673	3	1	0	27	2	2
034B00039L	7	159	30	53	31815	3	1	22	11	2	2

036B00025N	12	114	44	51	5190	3	1	10	20	2	2
036B00104N	12	968	82	37	6660	3	1	21	30	2	2
036B00106N	12	409	82	37	9190	3	1	34	32	2	2
036B00142N	12	245	32	13	5700	3	1	4	14	2	2
037B00093R	5	766	32	26	9571	3	1	18	44	2	2
039B00027R	6	128	38	48	16202	3	1	30	12	2	2
042B00106N	1	208	31	54	7220	3	1	0	40	2	2
042B00190N	1	264	20	61	557	3	1	2	30	2	2
042B00265N	1	77	22	16	89	3	1	6	18	2	2
045B00053N	9	225	30	31	2343	3	1	22	50	2	2
048B00180N	11	204	44	15	5294	3	1	10	17	2	2
051B00133N	2	167	44	30	6860	3	1	6	50	2	2
052B00038N	5	294	32	47	3952	3	1	18	10	2	2
053B00021N	1	198	30	67	894	3	1	4	24	2	2
056B00146L	5	72	29	45	2759	3	1	23	9	2	2

058B00044N	12	99	26	73	984	3	1	12	40	2	2
058B00067N	12	202	82	28	13711	3	1	34	16	2	2
063B00107N	11	306	98	15	19053	3	1	1	11	2	2
070B00038N	1	99	24	74	740	3	1	7	32	2	2
070B00063L	1	1731	39	38	12967	3	1	50	50	2	2
073B00015N	1	66	22	46	1379	3	1	14	50	2	2
073B00054N	1	115	22	64	1488	3	1	1	50	2	2
073B00055N	1	152	22	64	1488	3	1	8	50	2	2
073B00104R	1	170	38	43	13810	3	1	19	50	2	2
073B00106N	1	115	88	43	20078	3	1	5	32	2	2
073B00111L	1	121	39	40	21903	3	1	13	50	2	2
073B00112R	1	196	39	40	18580	3	1	0	35	2	2
079B00017N	1	99	19	77	3152	3	1	12	16	2	2
079B00019N	1	165	19	77	3152	3	1	4	15	2	2
079B00056N	1	144	28	60	9876	3	1	15	40	2	2

079B00117R	1	216	39	39	13455	3	1	21	46	2	2
079B00146N	1	297	48	11	2327	3	1	4	50	2	2
097B00017L	10	265	30	46	12600	3	1	24	13	2	2
097B00105N	10	302	86	33	21600	3	1	21	32	2	2
098B00053N	12	280	29	50	2208	3	1	4	50	2	2
098B00152N	12	355	27	34	100	3	1	22	50	2	2
098B00168N	12	269	32	31	1442	3	1	21	50	2	2
098B00176N	12	139	40	33	36200	3	1	22	50	2	2
098B00185L	12	223	51	27	13250	3	1	18	42	2	2
106B00034N	5	159	24	55	1406	3	1	14	16	2	2
106B00059R	5	226	30	55	20577	3	1	5	13	2	2
114B00052L	3	194	31	43	10104	3	1	10	18	2	2
117B00068N	2	221	26	47	79	3	1	22	23	2	2
119B00049N	10	172	30	52	4060	3	1	13	31	2	2
003B00034N	7	129	26	44	104	3	1	13	15	2	3

008B00018N	6	279	22	75	466	3	1	7	45	2	3
019B00049L	6	354	56	38	50374	3	1	50	15	2	3
019B00053L	6	218	64	38	58300	3	1	20	40	2	3
021B00044N	6	285	44	41	2350	3	1	26	25	2	3
025B00058R	7	159	30	53	5724	3	1	22	9	2	3
030B00045N	2	32	13	53	10608	3	1	1	40	2	3
034B00026N	7	211	91	46	41500	3	1	15	11	2	3
036B00144N	12	242	40	13	1333	3	1	2	15	2	3
045B00057N	9	323	28	30	1862	3	1	15	17	2	3
052B00050L	5	360	32	47	16709	3	1	39	6	2	3
054B00095L	2	318	34	54	9701	3	1	30	40	2	3
056B00147R	5	72	38	45	40466	3	1	10	20	2	3
056B00251N	5	188	142	45	59900	3	1	40	50	2	3
056B00290N	5	940	72	40	28800	3	1	23	43	2	3
056B00478N	5	100	106	12	59900	3	1	22	20	2	3

064B00055L	12	312	43	38	4375	3	1	23	50	2	3
073B00095N	1	389	44	59	16000	3	1	0	46	2	3
075B00053N	2	241	20	62	92	3	1	15	42	2	3
075B00057N	2	190	26	59	78	3	1	12	40	2	3
076B00105L	7	320	60	12	26950	3	1	10	20	2	3
081B00068N	9	157	35	16	1631	3	1	5	50	2	3
087B00015N	7	165	20	61	1281	3	1	11	17	2	3
105B00120L	7	268	60	23	28030	3	1	10	30	2	3
106B00066L	5	195	30	55	19078	3	1	22	23	2	3
036B00084L	12	562	28	52	7051	2	1	15	20	2	2
018B00111N	1	88	82	27	24185	3	2	3	42	2	1
018B00113N	1	170	28	27	716	3	2	5	50	2	1
036B00128N	12	319	82	25	5254	3	2	35	50	2	1
037B00099N	5	497	44	20	4280	3	2	50	26	2	1
042B00164N	1	198	26	48	75	3	2	17	50	2	1

042B002 16N	1	106	30	31	1350	3	2	9	16	2	1
042B002 47N	1	30	43	23	2338	3	2	3	50	2	1
042B002 49N	1	36	43	23	2338	3	2	10	50	2	1
045B000 67N	9	294	28	25	968	3	2	18	44	2	1
053B000 68N	1	237	26	48	24	3	2	30	49	2	1
058B000 71N	12	68	25	24	214	3	2	2	46	2	1
064B000 70N	12	89	29	28	426	3	2	4	50	2	1
067B000 87N	12	120	38	36	2119	3	2	12	23	2	1
070B000 45N	1	150	30	46	3130	3	2	41	12	2	1
072B000 38N	1	234	28	38	1240	3	2	31	15	2	1
073B001 31N	1	162	28	31	987	3	2	0	22	2	1
073B001 49N	1	33	34	22	1790	3	2	8	50	2	1
079B000 76L	1	519	30	48	8640	3	2	12	50	2	1
080B000 22N	12	312	42	29	5673	3	2	22	25	2	1
004B000 60N	1	375	44	25	3500	3	2	50	50	2	2

007B00109N	11	326	28	32	697	3	2	6	34	2	2
018B00119N	1	75	46	22	744	3	2	13	39	2	2
019B00064N	6	77	26	27	104720	3	2	0	38	2	2
028B00052N	1	224	34	38	517	3	2	0	47	2	2
034B00027L	7	135	38	46	36647	3	2	18	10	2	2
036B00135N	12	615	30	23	6674	3	2	46	30	2	2
042B00158R	1	97	38	48	3805	3	2	8	40	2	2
042B00168R	1	132	38	48	3205	3	2	15	40	2	2
042B00243N	1	68	32	26	2338	3	2	0	50	2	2
054B00014L	2	157	38	47	5451	3	2	14	50	2	2
054B00090N	2	174	24	46	354	3	2	12	19	2	2
061B00078N	11	506	34	37	2070	3	2	12	38	2	2
061B00091L	11	303	40	25	6650	3	2	30	30	2	2
079B00075R	1	291	30	48	8640	3	2	13	50	2	2
091B00055N	9	402	28	25	810	3	2	43	28	2	2

093B00054N	5	47	28	18	321	3	2	0	33	2	2
097B00113N	10	344	28	27	4685	3	2	0	40	2	2
098B00257R	12	907	41	9	7315	3	2	37	50	2	2
015B00090N	5	331	40	17	12200	3	2	6	20	2	3
036B00120N	12	586	34	28	8043	3	2	50	50	2	3
048B00140N	11	189	24	35	1174	3	2	8	20	2	3
056B00414N	5	210	135	26	117000	3	2	12	39	2	3
056B00495N	5	282	124	5	54047	3	2	2	23	2	3
057B00025R	7	198	40	29	16750	3	2	42	10	2	3
059B00082N	6	281	70	30	20897	3	2	14	50	2	3
108B00037N	5	323	278	31	676	3	2	14	32	2	3
113B00102N	2	173	39	18	1753	3	2	3	17	2	3
004B00057N	1	90	40	30	6871	1	1	0	0	4	1
005B00010N	3	25	35	90	4620	1	1	4	0	4	1
009B00024N	7	86	24	65	237	1	1	7	0	4	1

018B00025N	1	443	30	59	7115	1	1	2	0	4	1
020B00066N	1	69	76	12	2540	1	1	0	0	4	1
021B00023N	6	34	23	85	1610	1	1	7	0	4	1
028B00013N	1	212	19	82	741	1	1	9	0	4	1
033B00036N	10	81	28	32	1160	1	1	10	0	4	1
034B00154N	7	57	54	16	4973	1	1	13	0	4	1
036B00152N	12	200	24	5	2192	1	1	24	0	4	1
064B00031N	12	48	26	57	494	1	1	10	0	4	1
064B00083N	12	38	29	18	90	1	1	2	0	4	1
067B00046N	12	99	22	67	1334	1	1	4	0	4	1
070B00068N	1	83	28	33	617	1	1	0	0	4	1
073B00122N	1	256	44	40	4385	1	1	12	0	4	1
076B00100N	7	40	43	15	3760	1	1	13	0	4	1
076B00101N	7	188	29	14	688	1	1	10	0	4	1
079B00037N	1	67	23	83	2667	1	1	5	0	4	1

083B00039N	10	69	27	13	475	1	1	0	0	4	1
086B00032N	3	38	20	61	787	1	1	6	0	4	1
087B00008N	7	66	26	28	4490	1	1	0	0	4	1
091B00062N	9	131	48	13	3910	1	1	0	0	4	1
095B00003N	10	66	20	76	787	1	1	4	0	4	1
097B00012L	10	504	30	46	6418	1	1	0	0	4	1
097B00042N	10	261	26	54	706	1	1	11	0	4	1
098B00136N	12	76	26	56	4730	1	1	7	0	4	1
098B00138N	12	318	27	65	5655	1	1	5	0	4	1
098B00198N	12	88	40	25	1460	1	1	10	0	4	1
099B00049N	10	231	14	53	50	1	1	0	0	4	1
119B00071N	10	88	28	14	77	1	1	0	0	4	1
001B00084N	8	324	38	7	4899	1	1	9	0	4	2
003B00059N	7	37	33	11	2770	1	1	12	0	4	2
005B00011N	3	45	34	87	4762	1	1	6	0	4	2

008B00067N	6	65	28	29	3516	1	1	5	0	4	2
008B00089N	6	83	30	11	225	1	1	20	0	4	2
009B00004N	7	132	26	67	5500	1	1	8	0	4	2
019B00038N	6	362	44	40	2738	1	1	0	0	4	2
019B00043R	6	240	84	41	29552	1	1	5	0	4	2
019B00050N	6	313	36	38	7828	1	1	10	0	4	2
024B00156N	2	40	23	16	732	1	1	16	0	4	2
025B00105N	7	263	140	9	20431	1	1	10	0	4	2
034B00010N	7	443	16	60	1370	1	1	20	0	4	2
035B00095N	9	100	48	8	2862	1	1	6	0	4	2
036B00006N	12	159	20	77	2726	1	1	10	0	4	2
036B00105N	12	491	82	37	9910	1	1	0	0	4	2
039B00029N	6	245	26	48	141	1	1	20	0	4	2
040B00040N	7	257	48	12	4295	1	1	23	0	4	2
042B00274N	1	134	65	12	9314	1	1	2	0	4	2

048B000 30N	11	140	20	51	1290	1	1	2	0	4	2
049B000 27N	6	34	14	79	679	1	1	4	0	4	2
049B000 36N	6	78	19	83	761	1	1	7	0	4	2
052B000 56N	5	63	23	40	1285	1	1	0	13	4	2
055B000 07N	11	66	24	80	859	1	1	3	0	4	2
055B000 38N	11	68	27	27	415	1	1	5	0	4	2
056B003 67N	5	38	38	33	1860	1	1	4	0	4	2
057B000 32N	7	111	35	14	1230	1	1	0	0	4	2
058B000 47N	12	295	24	79	5286	1	1	2	0	4	2
059B001 12N	6	28	14	9	2137 9	1	1	0	0	4	2
060B000 42N	12	53	22	54	1125	1	1	10	0	4	2
060B000 77N	12	48	38	12	2300	1	1	13	0	4	2
061B000 16N	11	99	24	69	4020	1	1	6	0	4	2
061B000 37N	11	144	19	83	625	1	1	14	0	4	2
061B000 81R	11	159	40	36	7700	1	1	0	0	4	2

063B00039R	11	185	38	47	18960	1	1	0	0	4	2
063B00043L	11	480	30	46	18960	1	1	5	0	4	2
063B00097N	11	108	32	36	8054	1	1	12	0	4	2
066B00033N	11	124	24	63	2450	1	1	10	0	4	2
067B00031N	12	116	19	82	714	1	1	8	0	4	2
072B00005N	1	62	19	83	445	1	1	7	0	4	2
072B00051N	1	26	14	39	7288	1	1	7	0	4	2
073B00026N	1	43	28	60	6810	1	1	2	0	4	2
076B00008N	7	172	28	59	12100	1	1	17	0	4	2
077B00085N	10	224	44	8	1364	1	1	17	0	4	2
079B00035N	1	129	23	83	1360	1	1	4	0	4	2
079B00047N	1	172	19	83	1197	1	1	4	0	4	2
079B00081N	1	141	28	44	836	1	1	14	0	4	2
081B00047N	9	46	25	38	307	1	1	4	0	4	2
086B00056N	3	92	40	11	2760	1	1	15	0	4	2

094B00031N	6	60	25	29	216	1	1	10	0	4	2
095B00043N	10	101	40	8	607	1	1	15	0	4	2
097B00058N	10	143	22	58	1444	1	1	12	0	4	2
105B00021N	7	53	29	75	5690	1	1	0	0	4	2
105B00129N	7	114	30	18	1330	1	1	0	0	4	2
106B00090N	5	165	48	17	21900	1	1	12	0	4	2
110B00018N	3	43	28	54	1870	1	1	18	0	4	2
112B00035N	5	269	28	16	253	1	1	3	0	4	2
118B00022N	11	140	20	83	2519	1	1	12	0	4	2
118B00031N	11	120	24	80	7960	1	1	26	0	4	2
003B00011N	7	216	23	85	3260	1	1	6	0	4	3
003B00056N	7	264	28	20	1241	1	1	0	0	4	3
005B00045N	3	83	26	45	409	1	1	10	0	4	3
007B00062N	11	60	18	54	813	1	1	19	0	4	3
008B00075N	6	573	26	25	133930	1	1	14	0	4	3

009B00061N	7	35	27	28	1139	1	1	2	0	4	3
009R00605N	7	77	12	85	68	1	1	20	0	4	3
017B00026N	2	48	19	82	303	1	1	15	0	4	3
022B00035N	9	392	102	88	5710	1	1	3	0	4	3
022B00160N	9	36	40	11	2810	1	1	1	0	4	3
024B00064N	2	46	22	56	345	1	1	7	0	4	3
025B00033N	7	152	24	65	593	1	1	4	0	4	3
025B00102N	7	80	15	13	180	1	1	4	0	4	3
034B00036N	7	112	58	56	13670	1	1	14	0	4	3
034B00123N	7	204	68	34	16317	1	1	27	0	4	3
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041B00051N	6	330	35	13	5720	1	1	12	0	4	3
057B00024N	7	174	56	29	13100	1	1	15	0	4	3
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064B00038N	12	475	12	45	1273	1	1	0	0	4	3
067B00060N	12	48	24	64	1600	1	1	6	0	4	3
067B00096N	12	48	12	35	1900	1	1	0	0	4	3
071B00083N	3	125	26	27	90	1	1	5	0	4	3
075B00072N	2	26	22	22	164	1	1	0	0	4	3
076B00012N	7	111	24	81	12600	1	1	7	0	4	3
084B00043N	7	127	35	18	187	1	1	0	0	4	3
084B00047N	7	52	26	16	187	1	1	0	0	4	3
098B00058N	12	53	30	57	2020	1	1	5	0	4	3
098B00092N	12	46	22	48	3382	1	1	0	0	4	3
105B00046N	7	63	23	45	483	1	1	12	0	4	3
003B00007R	7	1088	30	50	8643	3	1	50	0	4	2
019B00044L	6	283	66	41	29552	3	1	40	0	4	2
019B00045N	6	494	25	41	59103	3	1	50	0	4	2
057B00012N	7	185	24	51	1460	3	1	15	0	4	2

103B000 56L	9	156	40	47	6000	3	1	50	0	4	2
019B000 48L	6	285	52	44	4407 5	3	1	50	0	4	3
034B000 32L	7	159	30	53	3181 4	3	1	38	0	4	3
067B000 08N	12	205	30	50	7232	3	1	7	0	4	3
063B000 25N	11	132	26	73	1330 1	2	1	6	0	4	3
002B000 12N	3	225	30	50	3450	2	1	14	0	4	1
005B000 47N	3	100	20	62	204	2	1	6	0	4	1
012B000 17N	6	152	20	60	260	2	1	6	0	4	1
033B000 15N	10	189	24	56	546	2	1	5	0	4	1
033B000 23N	10	134	22	59	1070	2	1	10	0	4	1
060B000 60N	12	231	25	45	801	2	1	5	0	4	1
061B000 49N	11	76	22	66	130	2	1	5	0	4	1
067B000 97N	12	67	40	35	1185	2	1	12	0	4	1
097B000 46N	10	100	12	69	383	2	1	5	0	4	1
111B000 60N	1	448	39	6	704	2	1	0	0	4	1

005B000 95R	3	289	42	13	1875	2	1	10	0	4	2
008B000 26N	6	66	22	62	1557	2	1	4	0	4	2
008B000 32N	6	279	26	48	1830	2	1	0	0	4	2
008B000 40L	6	159	107	55	3169 2	2	1	6	0	4	2
008B000 42L	6	307	22	48	9079 3	2	1	18	0	4	2
008B000 78L	6	159	73	22	4539 7	2	1	12	0	4	2
008B000 80L	6	159	73	23	5857 1	2	1	4	0	4	2
010B000 73L	9	246	42	8	9580	2	1	8	0	4	2
021B000 06N	6	319	26	48	270	2	1	18	0	4	2
025B000 42N	7	192	22	61	762	2	1	2	0	4	2
026B000 49N	11	129	23	57	1742	2	1	9	0	4	2
028B000 29N	1	89	20	65	74	2	1	4	0	4	2
032B000 20N	9	114	22	57	485	2	1	7	0	4	2
034B000 38L	7	199	30	56	2803 8	2	1	15	0	4	2
039B000 14N	6	350	28	48	1419	2	1	18	0	4	2

041B00014N	6	321	24	82	1450	2	1	8	0	4	2
049B00017N	6	404	90	57	1370	2	1	18	0	4	2
052B00048N	5	144	24	60	460	2	1	5	0	4	2
055B00020N	11	101	20	65	315	2	1	9	0	4	2
063B00002N	11	252	24	74	6967	2	1	19	0	4	2
066B00013N	11	212	21	71	3080	2	1	10	0	4	2
067B00032N	12	116	19	81	714	2	1	8	0	4	2
096B00001N	6	630	24	79	2841	2	1	6	0	4	2
096B00008N	6	133	26	4	2851	2	1	16	0	4	2
096B00026N	6	159	22	61	1153	2	1	7	0	4	2
097B00035N	10	99	22	67	4737	2	1	3	0	4	2
097B00043N	10	66	25	69	1220	2	1	2	0	4	2
098B00005N	12	159	22	58	267	2	1	4	0	4	2
106B00062L	5	245	30	55	27228	2	1	15	0	4	2
110B00011N	3	121	28	83	3497	2	1	3	0	4	2

114B00005N	3	200	54	61	22269	2	1	25	0	4	2
118B00044N	11	530	26	65	10100	2	1	30	0	4	2
118B00046L	11	172	38	48	18250	2	1	13	0	4	2
118B00090N	11	192	26	67	11773	2	1	0	0	4	2
003B00022N	7	236	26	50	12067	2	1	11	0	4	3
009B00008N	7	129	20	76	1320	2	1	12	0	4	3
009B00032N	7	129	28	49	1656	2	1	16	0	4	3
011B00047N	9	70	26	32	7770	2	1	6	0	4	3
019B00030N	6	114	24	60	3600	2	1	5	0	4	3
028B00024N	1	198	14	67	198	2	1	3	0	4	3
034B00003N	7	144	30	51	15742	2	1	10	0	4	3
034B00021L	7	134	24	53	31814	2	1	18	0	4	3
034B00049N	7	100	26	64	2597	2	1	8	0	4	3
034B00078R	7	132	50	51	25648	2	1	20	0	4	3
037B00060R	5	213	30	55	18350	2	1	30	0	4	3

041B00011N	6	241	24	82	3430	2	1	12	0	4	3
045B00025N	9	225	25	73	1546	2	1	14	0	4	3
056B00369N	5	282	84	29	10098	2	1	11	0	4	3
061B00084N	11	79	28	32	2070	2	1	27	0	4	3
066B00036N	11	185	24	58	530	2	1	8	0	4	3
071B00047N	3	364	24	79	8003	2	1	26	0	4	3
087B00012N	7	100	25	62	1881	2	1	7	0	4	3
105B00020N	7	216	26	27	7939	2	1	8	0	4	3
026B000108N	11	144	40	22	13035	1	2	11	0	4	1
026B00109N	11	63	32	22	379	1	2	9	0	4	1
028B00058N	1	36	41	31	4000	1	2	18	0	4	1
058B00081N	12	68	41	18	1650	1	2	0	0	4	1
059B00098N	6	247	28	17	340	1	2	0	0	4	1
060B00058N	12	341	33	43	5368	1	2	50	0	4	1
063B00110N	11	115	28	16	670	1	2	5	0	4	1

064B00066N	12	240	30	31	566	1	2	0	0	4	1
067B00111N	12	142	30	30	2825	1	2	6	0	4	1
067B00122N	12	213	33	23	778	1	2	4	0	4	1
076B00089N	7	53	28	22	583	1	2	9	0	4	1
098B00239N	12	108	30	17	5760	1	2	10	0	4	1
110B00040L	3	83	42	17	2440	1	2	4	0	4	1
025B00100N	7	87	40	20	4733	1	2	17	0	4	2
028B00063N	1	73	44	26	3180	1	2	10	0	4	2
032B00035N	9	906	44	16	3200	1	2	20	0	4	2
049B00069N	6	102	40	18	2320	1	2	2	0	4	2
056B00453N	5	46	31	19	784	1	2	3	0	4	2
097B00118N	10	34	28	19	1334	1	2	7	0	4	2
098B00230N	12	1023	44	20	8760	1	2	0	0	4	2
101B00017N	6	289	24	26	190	1	2	13	0	4	2
105B00142R	7	78	42	8	5150	1	2	8	0	4	2

008B00009N	6	276	82	55	52458	1	2	0	0	4	3
008B00065N	6	67	28	33	912	1	2	16	0	4	3
041B00047N	6	219	65	17	29700	1	2	3	0	4	3
056B00393N	5	99	149	27	171000	1	2	0	0	4	3
093B00049N	5	92	29	29	2356	1	2	7	0	4	3
118B00063R	11	485	30	57	16246	3	2	40	0	4	2
070B00075N	1	71	44	22	3927	2	2	3	0	4	2
086B00053N	3	140	32	19	2760	2	2	5	0	4	2
103B00077N	9	149	30	27	5550	2	2	11	0	4	2
105B00107R	7	296	47	28	11753	2	2	5	0	4	2
105B00108R	7	358	62	27	11508	2	2	13	0	4	2
022B00075N	9	185	11.2	51	1921	1	1	20	0	3	3
053B00059N	1	231	24	60	275	3	1	10	50	3	1
040B00004N	7	154	20	67	2770	3	1	3	21	3	3
042B00118N	1	99	23	81	775	1	1	6	0	3	1

042B00093N	1	38	28	59	5160	1	1	8	40	3	2
007B00101N	11	96	23	37	1191	1	1	20	0	3	3
002B00009N	3	363	26	52	197	3	1	24	41	3	1
004B00039N	1	99	24	57	254	3	1	5	40	3	1
004B00051N	1	99	24	55	240	3	1	5	50	3	1
013B00039N	10	406	24	56	1410	3	1	25	24	3	1
018B00102N	1	365	44	32	9198	3	1	17	50	3	1
018B00122N	1	54	22	18	392	3	1	10	12	3	1
018B00124N	1	58	22	18	54	3	1	10	12	3	1
020B00040N	1	99	24	53	194	3	1	2	39	3	1
028B00049N	1	114	24	55	294	3	1	7	49	3	1
036B00110N	12	798	44	37	2183	3	1	20	13	3	1
036B00125N	12	192	30	27	199	3	1	4	50	3	1
036B00153N	12	200	24	5	2192	3	1	12	23	3	1
038B00015N	1	196	38	48	1730	3	1	22	50	3	1

038B00048N	1	159	22	44	40	3	1	3	20	3	1
038B00084N	1	78	26	22	93	3	1	8	48	3	1
042B00028N	1	208	26	48	341	3	1	23	50	3	1
042B00057N	1	84	26	56	825	3	1	3	40	3	1
042B00129N	1	114	24	56	673	3	1	3	50	3	1
042B00172N	1	241	26	48	200	3	1	20	38	3	1
042B00196N	1	114	24	55	730	3	1	4	49	3	1
042B00222N	1	180	28	28	2338	3	1	5	50	3	1
042B00224N	1	135	28	28	2338	3	1	5	50	3	1
042B00261N	1	71	29	16	419	3	1	0	21	3	1
053B00036N	1	87	19	83	130	3	1	12	40	3	1
053B00098N	1	227	26	18	239	3	1	0	23	3	1
053B00100N	1	212	28	16	140	3	1	2	28	3	1
059B00053L	6	256	62	21	96177	3	1	0	10	3	1
067B00038N	12	411	20	75	778	3	1	0	32	3	1

067B00082N	12	203	44	41	10441	3	1	14	12	3	1
067B00102N	12	149	77	36	13754	3	1	10	20	3	1
067B00103N	12	291	44	36	13754	3	1	10	20	3	1
068B00054N	9	76	20	63	245	3	1	7	22	3	1
071B00086N	3	96	27	23	218	3	1	7	17	3	1
073B00101L	1	133	38	43	14045	3	1	23	50	3	1
073B00158N	1	64	23	15	174	3	1	2	39	3	1
073B00164R	1	506	42	15	6461	3	1	3	17	3	1
079B00089N	1	132	24	60	504	3	1	7	41	3	1
079B00144R	1	232	28	16	4190	3	1	9	11	3	1
097B00100N	10	288	82	34	9243	3	1	10	10	3	1
098B00201R	12	157	45	37	16969	3	1	8	17	3	1
006B00050R	9	157	40	48	8071	3	1	13	7	3	2
007B00121N	11	208	30	27	1854	3	1	0	37	3	2
010B00074N	9	293	29	8	15621	3	1	10	45	3	2

016B000 19N	3	76	24	77	147	3	1	8	20	3	2
018B000 90N	1	99	24	52	277	3	1	5	37	3	2
018B001 26N	1	163	34	11	1393	3	1	0	50	3	2
028B000 48N	1	99	24	55	79	3	1	4	23	3	2
034B001 58N	7	262	56	12	4397	3	1	3	26	3	2
035B000 97N	9	266	54	9	2862	3	1	31	8	3	2
036B000 23N	12	114	44	51	5190	3	1	20	14	3	2
036B000 60N	12	99	22	62	440	3	1	4	18	3	2
036B000 79N	12	436	30	46	5756	3	1	12	50	3	2
036B000 90N	12	396	34	38	2800	3	1	22	50	3	2
036B001 07N	12	235	82	37	1202 2	3	1	28	20	3	2
036B001 09N	12	620	82	37	1204 0	3	1	29	47	3	2
036B001 14N	12	187	70	37	1197 0	3	1	23	47	3	2
036B001 39N	12	105	84	15	1138 2	3	1	8	10	3	2
036B001 40N	12	250	86	15	1138 2	3	1	2	22	3	2

042B000 09N	1	213	30	48	3280	3	1	15	40	3	2
042B000 62N	1	228	22	60	1390	3	1	3	40	3	2
042B001 85N	1	112	20	62	393	3	1	3	42	3	2
053B000 14N	1	132	20	78	765	3	1	8	30	3	2
053B000 15N	1	165	20	78	765	3	1	9	30	3	2
053B000 41N	1	195	30	84	707	3	1	13	38	3	2
056B001 53N	5	220	38	49	7760 4	3	1	25	50	3	2
058B000 41N	12	827	30	53	6204	3	1	2	50	3	2
058B000 50R	12	129	44	46	5650	3	1	20	34	3	2
059B001 06L	6	479	40	13	8948	3	1	18	7	3	2
059B001 08N	6	279	85	14	1789 6	3	1	7	6	3	2
060B000 12N	12	161	24	77	1905	3	1	14	18	3	2
061B000 68N	11	174	30	51	6896	3	1	34	33	3	2
061B000 82R	11	225	40	36	9350	3	1	7	43	3	2
064B000 27N	12	144	26	53	1000	3	1	2	36	3	2

067B00130N	12	451	82	15	6250	3	1	0	20	3	2
073B00009N	1	294	44	43	7800	3	1	11	50	3	2
073B00059N	1	204	42	55	8050	3	1	0	41	3	2
073B00079N	1	132	24	63	3435	3	1	10	40	3	2
073B00093N	1	238	50	64	16364	3	1	30	40	3	2
079B00011N	1	152	30	54	3262	3	1	11	50	3	2
079B00097N	1	114	28	47	2351	3	1	11	39	3	2
079B00118R	1	2108	39	41	13155	3	1	40	50	3	2
080B00013N	12	200	24	57	1560	3	1	6	50	3	2
080B00018N	12	99	24	50	1840	3	1	0	50	3	2
088B00010N	10	84	20	78	2000	3	1	4	26	3	2
103B00093N	9	303	76	9	22200	3	1	18	27	3	2
105B00133N	7	171	40	16	4590	3	1	3	5	3	2
114B00087N	3	283	120	13	46360	3	1	2	12	3	2
114B00090R	3	128	59	13	21380	3	1	1	12	3	2

118B000 45L	11	674	30	50	1549 6	3	1	32	39	3	2
120B000 24L	7	165	39	42	1940 0	3	1	20	20	3	2
007B001 43N	11	99	31	16	156	3	1	2	11	3	3
008B000 21N	6	318	30	57	1966	3	1	25	50	3	3
008B000 73N	6	640	26	25	1339 30	3	1	32	18	3	3
011B000 38L	7	509	44	44	1140 0	3	1	39	3	3	3
018B001 37R	1	345	42	6	1936	3	1	6	13	3	3
035B000 91N	9	95	30	12	148	3	1	2	8	3	3
036B000 21N	12	114	44	51	1160 0	3	1	20	30	3	3
036B000 36N	12	99	28	56	1989	3	1	15	50	3	3
036B000 78N	12	371	24	53	2740	3	1	0	50	3	3
036B001 38N	12	98	26	18	600	3	1	0	14	3	3
040B000 38N	7	153	30	14	412	3	1	11	30	3	3
045B000 77N	9	236	48	12	5209	3	1	7	5	3	3
056B001 56L	5	284	30	49	7444 4	3	1	22	50	3	3

056B00158N	5	385	30	49	148888	3	1	38	50	3	3
056B00372R	5	151	40	28	32285	3	1	18	9	3	3
057B00031N	7	128	28	14	4410	3	1	4	9	3	3
059B00038L	6	159	88	55	77669	3	1	30	46	3	3
064B00063N	12	201	34	32	484	3	1	15	50	3	3
073B00061N	1	214	30	55	19500	3	1	0	50	3	3
079B00114R	1	193	47	39	13000	3	1	24	11	3	3
081B00036N	9	210	26	52	1091	3	1	32	49	3	3
084B00046N	7	172	35	15	698	3	1	2	6	3	3
087B00059N	7	354	40	18	6854	3	1	12	5	3	3
100B00029N	8	1208	26	64	5864	3	1	0	12	3	3
114B00085L	3	496	41	13	7875	3	1	7	6	3	3
118B00056R	11	141	38	50	12700	3	1	30	5	3	3
004B00067N	1	90	23	13	325	2	1	3	0	3	2
034B00094L	7	117	62	51	38754	2	1	5	4	3	2

012B00030N	6	244	44	26	4833	3	2	22	18	3	1
013B00071N	10	122	24	27	206	3	2	9	18	3	1
021B00034N	6	150	24	45	291	3	2	7	17	3	1
028B00064N	1	41	45	26	1710	3	2	10	33	3	1
041B00041N	6	403	24	26	121	3	2	10	30	3	1
042B00159L	1	97	38	48	3805	3	2	12	40	3	1
042B00217N	1	245	28	31	691	3	2	0	34	3	1
042B00238N	1	83	28	27	668	3	2	4	50	3	1
042B00239N	1	80	28	27	891	3	2	4	50	3	1
042B00254N	1	70	30	17	877	3	2	0	16	3	1
060B00056N	12	633	32	43	6191	3	2	38	4	3	1
060B00070N	12	168	32	27	1125	3	2	10	18	3	1
070B00046N	1	216	30	46	3130	3	2	47	50	3	1
071B00097L	3	204	43	20	1731	3	2	14	15	3	1
073B00064N	1	228	27	44	386	3	2	20	50	3	1

073B00138N	1	140	31	31	11200	3	2	17	48	3	1
076B00099N	7	93	93	17	34100	3	2	2	6	3	1
079B00128N	1	223	40	29	8842	3	2	13	50	3	1
079B00135N	1	51	28	22	255	3	2	7	45	3	1
088B00072N	10	141	46	33	6850	3	2	15	18	3	1
088B00081N	10	252	40	24	2550	3	2	3	23	3	1
098B00186N	12	289	28	29	1820	3	2	15	16	3	1
119B00062N	10	74	40	19	1507	3	2	3	25	3	1
015B00071N	5	289	24	29	50	3	2	18	6	3	2
030B00155N	2	206	86	18	14680	3	2	8	50	3	2
034B00164L	7	195	43	11	7728	3	2	18	16	3	2
042B00154R	1	208	24	48	7400	3	2	26	50	3	2
042B00162R	1	189	38	48	3205	3	2	14	40	3	2
042B00163L	1	97	38	48	3205	3	2	12	50	3	2
042B00165L	1	97	38	48	3205	3	2	13	50	3	2

042B00166R	1	208	38	48	3205	3	2	9	50	3	2
042B00170R	1	310	30	48	3775	3	2	16	50	3	2
042B00257N	1	67	39	16	2379	3	2	0	19	3	2
045B00082N	9	464	60	12	5209	3	2	20	30	3	2
049B00068N	6	310	52	20	4740	3	2	6	34	3	2
058B00058N	12	190	44	37	7715	3	2	15	36	3	2
058B00064N	12	134	32	32	10600	3	2	8	27	3	2
058B00068N	12	83	41	25	1150	3	2	6	15	3	2
066B00061N	11	324	30	29	2880	3	2	16	20	3	2
098B00196N	12	142	40	27	5180	3	2	4	35	3	2
107B00035N	3	170	76	31	3238	3	2	27	28	3	2
021B00045N	6	259	44	41	14200	3	2	19	36	3	3
022B00083R	9	357	38	44	10123	3	2	16	47	3	3
041B00048N	6	290	41	14	11500	3	2	4	7	3	3
047B00156N	4	303	44	19	5559	3	2	44	14	3	3

056B00426L	5	1030	85	26	58500	3	2	32	41	3	3
120B00038N	7	182	25	21	1710	3	2	13	10	3	3
018B00024N	1	87	23	70	2720	3	1	7	30	1	1
042B00201N	1	159	23	38	207	3	1	0	50	1	1
059B00081L	6	547	36	32	7537	3	1	10	50	1	1
064B00058N	12	93	34	36	457	3	1	9	39	1	1
067B00083N	12	343	62	41	9416	3	1	37	7	1	1
070B00065N	1	1467	25	63	6794	3	1	7	50	1	1
080B00039N	12	164	33	16	385	3	1	0	21	1	1
097B00056N	10	159	36	48	9663	3	1	20	19	1	1
111B00043N	1	262	27	42	61	3	1	27	28	1	1
003B00060N	7	254	133	12	14800	3	1	14	11	1	2
012B00008N	6	159	26	54	826	3	1	22	40	1	2
026B00061N	11	178	76	44	11724	3	1	27	7	1	2
032B00012N	9	114	24	65	250	3	1	2	40	1	2

033B000 19N	10	165	22	80	1570	3	1	5	30	1	2
036B000 37L	12	308	45	42	9850	3	1	24	50	1	2
036B000 77N	12	246	30	53	5930	3	1	0	50	1	2
042B001 28N	1	215	26	48	673	3	1	25	50	1	2
053B000 22N	1	185	24	74	1320	3	1	6	48	1	2
059B000 73N	6	207	40	37	2603	3	1	28	9	1	2
064B000 18N	12	121	20	78	808	3	1	4	34	1	2
079B000 23N	1	349 6	20	83	2200	3	1	10	30	1	2
098B002 56L	12	127 6	42	9	7350	3	1	50	20	1	2
036B000 08N	12	84	30	60	2890	3	1	2	30	1	3
036B000 86N	12	358	28	52	1270	3	1	30	50	1	3
051B000 73R	2	191	26	45	5000	3	1	27	34	1	3
051B000 74N	2	270	34	45	4610	3	1	23	33	1	3
051B000 76N	2	240	30	45	672	3	1	22	38	1	3
054B000 12R	2	174	38	47	6337	3	1	30	21	1	3

084B00014R	7	200	30	50	5250	3	1	20	14	1	3
018B00120N	1	140	44	19	6861	3	2	7	50	1	1
019B00067N	6	165	82	26	9757	3	2	17	40	1	1
053B00050N	1	222	28	48	278	3	2	16	50	1	1
042B00177L	1	211	38	48	4355	3	2	9	48	1	2
052B00075N	5	175	27	26	362	3	2	24	12	1	2
056B00314L	5	170	46	17	18250	3	2	36	7	1	2

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

```
GET
  FILE='C:\Users\jzh252\Desktop\Sample1.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.

Case Processing Summary

		N	Marginal 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%
	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

Model	-2 Log 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

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper 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.

Test of Parallel Lines[a]

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

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.

Case Processing Summary

		N	Marginal 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%
	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	
Subpopulation		87[a]	

a. The dependent variable has only one value observed in 87 (100.0%) subpopulations.

Model Fitting Information

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

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

Likelihood Ratio Tests

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of 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

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.

Parameter Estimates

SEVERITY[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower Bound	Upper 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]
	[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

Observed	Predicted 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%

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.

Case Processing Summary

		N	Marginal 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%
	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

Model	-2 Log 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

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper 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
EH	.005	.008	.307	1	.580	-.012	.021
FSD	.002	.008	.085	1	.771	-.013	.017
[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
[DISTRICT=9.00]	1.699	.424	16.091	1	.000	.869	2.529
[DISTRICT=10.00]	-1.236	.417	8.790	1	.003	-2.054	-.419
[DISTRICT=11.00]	.850	.369	5.302	1	.021	.126	1.573
[DISTRICT=12.00]	0[a]	.	.	0	.	.	.
[ABUT=1.00]	.570	.530	1.155	1	.282	-.469	1.609
[ABUT=2.00]	.706	.554	1.626	1	.202	-.379	1.792
[ABUT=3.00]	0[a]	.	.	0	.	.	.
[APPT=1.00]	.529	.219	5.825	1	.016	.099	.958
[APPT=2.00]	0[a]	.	.	0	.	.	.
[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	.	.	.

Link function: Logit.

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

Test of Parallel Lines[a]

Model	-2 Log 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.

Case Processing Summary

		N	Marginal 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%
	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	
Subpopulation		599[a]	

a. The dependent variable has only one value observed in 599 (100.0%) subpopulations.

Model Fitting Information

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC	BIC	-2 Log 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

Likelihood Ratio Tests

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	1080.788	1291.841	984.788[a]	.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

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.

Parameter Estimates

SEVERITY[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B) Lower Bound	Upper 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

[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]	-20.848	.000	.	1	.	8.827E-10	8.827E-10	8.827E-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.

Classification

	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%

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