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Roadside Grading Guidance

Kevin D. Schrum
University of Nebraska-Lincoln, kevin.schrum@huskers.unl.edu

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ROADSIDE GRADING GUIDANCE

by

Kevin D. Schrum

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ROADSIDE GRADING GUIDANCE

Kevin Dale Schrum, M.S.

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Adviser: Dean L. Sicking

Provisions for the design of roadside foreslopes are not readily available, and as a result, engineering judgment is often employed. Unfortunately, this can lead to inconsistent designs, where, inevitably, some designs will be too costly and other designs will be too dangerous. Therefore, a design guide was created to lend consistency to the design of these foreslopes while maintaining the most economical and safe design.

This design guide was prepared after conducting a benefit-cost analysis using the Roadside Safety Analysis Program (RSAP). A large test matrix was developed in an attempt to simulate the most possible scenarios, leaving interpolation to a minimum. However, before the analysis could be run, the severity indexes associated with foreslopes needed to be updated to accurately reflect vehicle damages and injury levels caused during an encroachment occurring at an average impact speed. Current indexes are overestimated because they were based on a survey given out to highway safety officials who were most likely biased toward high-speed accidents.

To update the severity indexes, accident data from the State of Ohio was analyzed using a program called Global Mapper, which allowed the user to measure topographical features, such as foreslopes, heights, and offsets. A method is presented to account for underreported accidents on flat slopes as well. Finally, equations for determining accident cost as a function of the traffic volume are given in conjunction with examples that demonstrate the use of these equations.

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Several people outside of MwRSF have played a role in the development of my education. First, my parents, Brad and Brenda Schrum, have instilled a sense of personal ambition and pride that have guided me through a high school diploma, bachelor's degree, master's degree, and, eventually, a Ph.D. Their love and support continue to be an immense source of energy both in and out of the classroom. My brother, Kody Schrum, who is currently serving in the Marine Corps and volunteering as a fire fighter in North Carolina, has shown me what a single person can do in this life. My other parents, Max and Kim Galyen, have given me so much, including a family of my own. My sisters, Meagan Shrewsbury and Brittany Galyen, and the rest of my family have given their support and kept Lyndsey company while I was away.

Finally, my wife, Lyndsey, has been the most constant and influential person in my life over the past eight years. She has used that influence to mold me into the person I am today, and I cannot express how grateful I am for it. Lyndsey, I love you more than I can express in this paragraph. To my Heavenly Father, thank You for my education, my home, my life, and my family.

To My Family,

Lyndsey, Eliza, and Joseph

For the Reminder of What is Important in Life

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1 INTRODUCTION

1.1 Problem Statement

Engineering judgment is used to design foreslopes, and as a result, there is very little consistency amongst engineers. Because of this inconsistency, an engineer may call for a slope that is flatter than is required or call for a guardrail when one is not needed. To determine the best course of action, a benefit-cost analysis would be required. Tools to conduct this benefit-cost analysis exist, such as the Roadside Safety Analysis Program (RSAP), but it can be cumbersome to apply to every possible highway scenario and difficult to implement amongst engineers statewide. With shrinking budgets, it has become expedient to develop a systematic approach to designing roadside geometries and safety appurtenances that economically create a safe environment.

A study has been conducted that estimated the severity of crashes involving roadside embankments, but the accuracy of that study is questionable [1]. The Roadside Design Guide (RDG) associated these encroachments with a severity index, but these severity indexes appear to be overestimated because they were determined using engineering judgment alone and were primarily based on incidents involving high-speed impacts [2]. More accurate severity indexes need to be incorporated into RSAP to establish correct accident costs associated with a crash that involves roadside slopes.

1.2 Objectives

First, the severity indexes associated with roadside embankments needed to be updated to accurately predict accident costs. Then, an extensive test matrix was constructed for use in RSAP using parameters that were most likely to influence accident costs as those parameters were allowed to change. Next, the results from this analysis were used to create equations for any scenario that could predict the accident cost, which in turn could be used in a benefit-cost analysis. Finally, a spreadsheet using Microsoft Excel was created to facilitate a quick and simple way to calculate accident costs.

2 LITERATURE REVIEW

2.1 Highway Safety

Vehicular fatalities in the United States have historically remained relatively constant, despite an ever-growing number of vehicular miles traveled. However, in 2009, the number of fatalities was 30,797 which was nearly 7,000 less than in 2007, and more than 3,000 less than in 2008 [3]. This decrease marks the largest of its kind over the past 15 years. This decrease was the result of several factors including safer vehicle designs, safer roadside designs, and potentially fewer recreational motorists due to rising fuel prices. However, the total number of vehicle miles traveled increased by 5 billion, resulting in a decrease in the number of fatalities per 100 million vehicle miles traveled (1.26 in 2008 to 1.13 in 2009) [3]. Of the 30,797 fatalities in 2009, 18,745 involved a single vehicle, and 9,891 of those fatalities were off the roadway [4]. The number of fatal crashes in which the first harmful event was a collision on an embankment was 1,018 which was 3.3 percent of all fatalities, but the total number of crashes in which the first harmful event was a collision with an embankment was 52,000, which represented only 0.9 percent of all accidents [4]. From this data, embankments were shown to be disproportionately high for fatal accidents. However, the percent of fatalities has decreased slightly from 2008, which had a 3.4 percent fatality rate when a collision with an embankment was the first harmful event [5]. Although the general trend of fatal accidents from year to year is one of improvement, the number of fatalities is still too high, indicating a need for more embankment design guidance based on actual accident data.

2.2 Monte Carlo Simulation Technique

The Monte Carlo method generates data from known probability distributions of important parameters, like encroachment location, speed and angle, vehicle type, and vehicle orientation. This technique allows its user to generate as much data as is required without ever running physical tests. As a result, thousands of simulations can be run in only seconds, generating the average number of impacts, the average speed and angle of the impact, and ultimately, the average accident costs, as determined from the crash cushion type and the severity of the impact. However, the actual number of simulations required to produce an indicative result is impossible to estimate beforehand. Instead, a block of simulations (for example 20,000 encroachments) is tested, and the accident cost is determined. Then another block is added, and the accident cost is checked for any changes from the first block. If that change is less than 1 percent (high convergence), the simulation ceases. Otherwise, the process is repeated until the convergence criterion is met. In addition to the end result (accident costs), the randomly generated parameters (encroachment location, speed and angle, vehicle type, and vehicle orientation) are checked for uniformity from one block to the next. This check ensures that the average accident costs are correct and that the simulation does not end too soon [6].

The Monte Carlo simulation technique was used because it is capable of simulating parameters that need to be combined. This combination creates an unpredictable probability distribution. However, the probability distribution of combined parameters is not needed in this technique. Only the distributions of the individual parameters are required. The Monte Carlo method is also very capable of simulating independent parameters. These parameters were selected based on separate random processes. They included vehicle type and vehicle orientation. These parameters were considered independent because there was no conclusive data that linked these parameters to other parameters. Dependent parameters must be combined into a common random number generation process. Speed and angle are connected by physical limitations while cornering. Also, the location of the encroachment depends on the segment in which the encroachment occurs, the location within the segment, the direction of travel, the lane in which the encroachment originates, and the direction of the encroachment [6].

Each of the parameters was scaled to be uniformly distributed (except encroachment location). Without this scaling, the probability of some of the severe impact conditions would likely eliminate some fatal or severe accidents from the scenario. Because these events have the largest effect on accident costs, they need to be included. Therefore, a scaling factor is applied to each cell that is assigned to a probability of occurrence for each parameter. Later, the average crash cost is divided by this scale factor to determine an average encroachment cost. This process has no effect on the actual average costs, but it dramatically reduces the effect of over- and under-sampling the extreme events. The distribution for encroachment location is not scaled because the encroachment may occur at any location along a segment (continuous parameter). Because of the endless possible locations for an encroachment, the probability of each location would be zero, and the scale factor would approach infinity. However, the probability distribution is still uniform because the segment is broken up into equal sub-segments, and each one has the same chance of producing an encroachment.

Random numbers are generated from a linear congruent generator and are used to create encroachment samples. A pseudo-code is created to generate numbers from a start point or seed number [7-8]. If the same seed number is used, the same random numbers will be generated. RSAP uses a dual generator, thus increasing the period of randomness; after which, the numbers are no longer random. Additionally, a shuffling process is used to increase the randomness of the output [9].

A drawback to this random process is that no two runs would be the same, in theory. Output is allowed to vary within the convergence criteria set by the user. Therefore, results cannot be viewed as deterministic. For example, if a benefit-cost (B/C) ratio between alternatives 1 and 2, with 1 being the do-nothing alternative, is 2.01, the engineer cannot conclude that it is always better to select alternative 2. The next attempted analysis may yield a B/C ratio of 1.99 without changing any parameters.

2.3 Accident Prediction

2.3.1 RSAP

RSAP uses two modules to predict accident events. First, the program must simulate an encroachment based on encroachment frequency data. Second, for each encroachment, RSAP determines if the vehicle will strike any fixed objects or slopes using the crash prediction module. Once a crash is predicted, it determines the severity of the impact using the crash severity module. From the severity, an average accident cost is determined, which in turn, is used to calculate the B/C ratio in the benefit-cost analysis.

First, an encroachment must be simulated. A study done by Cooper in the late 1970s was the basis for the encroachment module used in RSAP [10]. However, limitations to this study have forced researchers to modify the results. First, encroachments of less than about 13.1 ft (4.0 m) were undetectable due to a paved shoulders. The results were reanalyzed after excluding encroachments that extended less than 13.1 ft (4.0 m) laterally. It was estimated that encroachments were underreported by a ratio of 2.466 and 1.878 on two-lane undivided and multi-lane divided highways respectively, and the encroachment frequencies were adjusted upward accordingly [6]. Also, controlled and uncontrolled encroachments could not be distinguished. Examples of a controlled encroachment include implements of husbandry driving off the pavement or a vehicle pulled over to the side of the road to switch drivers. It was believed that these controlled encroachments are less in number than the uncontrolled encroachments. In fact, a study was done that examined the number of impacts on longitudinal barriers and the number of actual reported accidents. From that study, 60 percent of the accidents were reported to the police [11]. Therefore, the encroachment frequencies were again modified by multiplying the frequency by 0.60 [6]. The results of the Cooper data are shown in Figure 1. Additionally, adjustment factors are applied to the encroachment frequency for horizontal curvature, vertical grade, traffic growth, and any user-defined factor. For sharp curves, steep down grades, and larger traffic growths, the encroachment frequency is enlarged. However, the encroachment frequency is never reduced by any of these factors.

There are other competing encroachment models. First, Hutchinson and Kennedy conducted a study on a stretch of an interstate in Illinois in the 1960s [12]. Their data indicated the same approximate relationship between the traffic volume and the encroachment frequency as Cooper's results. However, new statistical tools have been developed and used by Davis to show that the Hutchinson and Kennedy results were influenced by the weather and by the sampling technique more than the traffic volume [13]. Because the Cooper data and the Hutchinson and Kennedy data show a similar trend, the statistical analysis that Davis used should be applied to Cooper's data as well to see if the encroachment frequency held a dependence on weather or sampling techniques.

Miaou proposed another method of predicting encroachment frequencies from accident data taken from single-vehicle, run-off-road accidents (SVRORA) in Alabama, Michigan, and Washington [14]. From those accidents, the probability of a SVRORA occurring for a given roadside could be estimated. By multiplying that probability by the traffic volume, the expected number of accidents for that roadside configuration could be estimated. From this accident model, and by using the traffic volume and length of the roadway segment, the encroachment frequency model was created. These results indicated a monotonic relationship between traffic volume and the encroachment frequency per year per mile, as opposed to the results presented by both Cooper and Hutchinson and Kennedy.

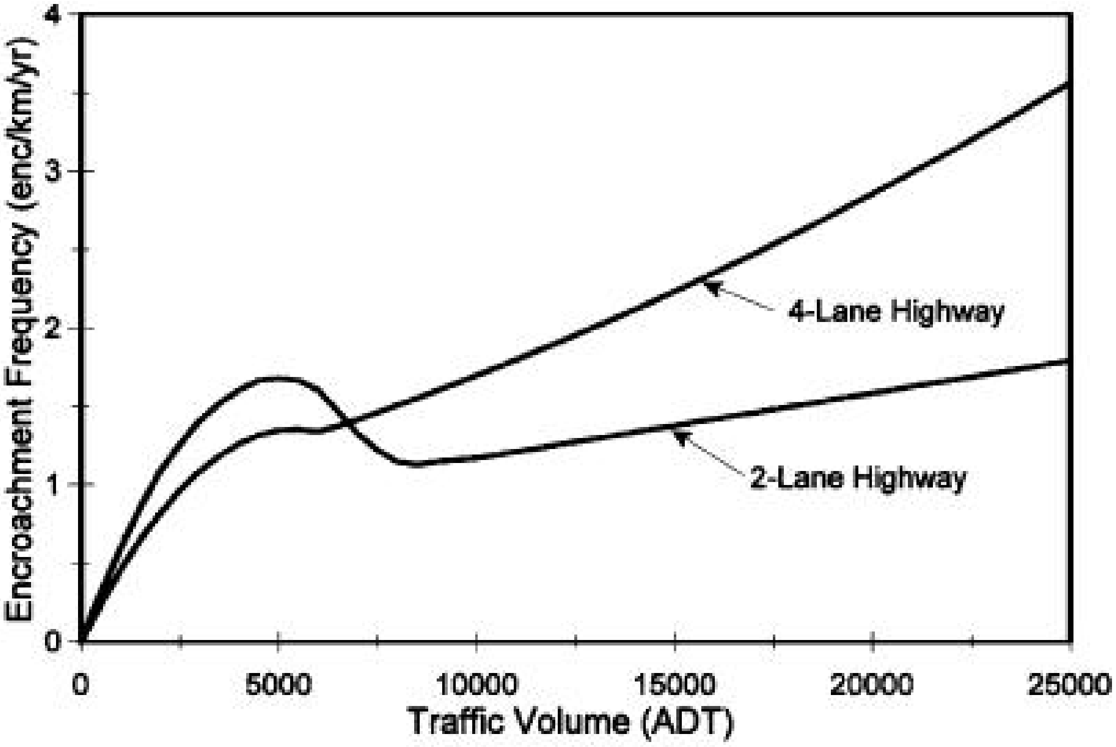


Figure 1. Cooper Encroachment Data [10]

After RSAP has predicted an encroachment, it must determine if a crash will occur. Not every encroachment will result in a crash. By using the speed and angle of the encroachment and the hazard layout, the program can determine if a hazard will be struck, and if so, if the vehicle will penetrate through the hazard and strike another hazard. Hazards that are programmed by the user are sorted by their longitudinal position relative to the beginning of the segment. Next, they are placed on the correct side of the road or in the median. Finally, they are moved laterally to the specified offset from the edge of the traveled way. Next, the vehicle swath must be determined. Based on the encroachment module, the vehicle speed, direction, and orientation were all simulated using the Monte Carlo method. If any object was in the vehicle swath, a crash was predicted. These objects were equipped with penetration data, such that, if the vehicle had enough energy, it could penetrate through the object and continue on, possibly striking another object. However, this study focused on foreslopes, where no penetration could have occurred. Therefore, a crash was predicted if the extent of lateral encroachment exceeded the offset to the edge of the slope.

This module assumes the vehicle maintains a constant angle throughout the event (i.e., a straight line) and a constant orientation. Also, the vehicle speed does not change as a result of braking. These three assumptions combine into one basic assumption. Driver behavior is ignored. This means that the driver’s attempt to maneuver away from the foreslope or to slow down before reaching the bottom are not considered. Also, RSAP currently does not modify severity indexes based on vehicle orientation, but it would be possible to modify the program to change the severities once more is known about how different orientations can affect the severity. In addition to using a straight-line encroachment, RSAP also does not attempt to predict a rollover on foreslopes. This is concerning because as much as 86 percent of all rollovers are the result of anything other than striking a fixed object [15]. Under the NCHRP Project 22-27, RSAP is being updated using Visual Basic and Excel [16]. In this update, curvi-linear encroachments will be included by randomly selecting one possible encroachment path. Currently, RSAP generates a random number that selects the speed and angle of the encroachment, but that angle remains constant throughout the simulation.

2.3.2 Other Accident Prediction Methods

Zegeer approached accident prediction in a different way. He determined a percent reduction in the number of crashes for several roadside features. Of particular note, he investigated the effect of sideslopes on single-vehicle accidents and on rollovers. He concluded that steeper slopes had higher accident rates and that slopes steeper than 4:1 had significantly higher rollover rates than slopes that were 1V:5H or flatter [17]. Even more importantly, slopes that were 3:1 or steeper had significantly higher single-vehicle accident rates than foreslopes that were 4:1 or flatter. This trend was also shown in the results outlined in this report. Using the same data that Miaou used (Alabama, Michigan, and Washington), he analyzed 595 accidents and created an equation that accounted for the steepness of the slope, the lane width, the roadside recovery distance, the traffic volume, and the shoulder width. Using this equation, he developed a table of percent reductions in the number of single-vehicle accidents. These reductions were used to reduce the number of known accidents on one slope to the number of expected accidents on another slope. His work was later modified slightly to create crash modification factors (CMF). These factors were first published in the NCHRP Report No. 617 and again in the Highway Safety Manual [18-19]. That is, instead of reducing the number of known accidents by 10 percent, the number of known accidents was multiplied by 0.90. The tabulated CMFs that were determined from Zegeer's work and applied to single-vehicle accidents are shown in Table 1.

Table 1. CMFs as They Appear in the Highway Safety Manual [19]

Table 13-19. Potential Crash Effects on Single Vehicle Crashes of Flattening Sideslopes

Treatment	**(Road Type)**	**Traffic Volume**	**Crash Type (Severity)**	**CMF**				
				Sideslope in Before Condition	**Sideslope in After Condition**			
					1V:4H	**1V:5H**	**1V:6H**	**1V:7H**
Flatten Sideslopes	Rural (Two-lane road)	Unspecified	Single Vehicle (Unspecified)	**1V:2H**	0.9	0.85	0.79	0.73
				1V:3H	0.92	0.86	0.81	0.74
				1V:4H		0.94	0.88	0.81
				1V:5H			0.94	0.86
				1V:6H				0.92

Base Condition: Existing sideslope in *before* condition.

2.4 Severity Indexes

Glennon and Tamburri may have been among the first researchers to begin studying what would become known as severity indexes. Glennon defined a severity index (SI) as "a numerical weighing scheme that ranks roadside obstacles by degree of accident consequence" [20]. Glennon and Tamburri developed an equation for determining the severity of an embankment based on the number of fatal accidents, injury accidents, and property damage only (PDO) accidents [21]. It used a weighted average that placed a large emphasis on fatal accidents and a smaller emphasis on injury accidents, as shown in Equation 1. Other than being included in the equation, no additional emphasis was placed on the PDO accidents.

$$SI = \frac{25\times(fatal\ accidents)+6\times(injury\ accidents)+(PDO\ accidents)}{(total\ accidents)} \qquad (1)$$

The results of that study demonstrated SI values that would be regarded as high in today's transportation safety community. Since the inception of that study, roadside geometries have been made safer by the implementation of better-performing safety features and the concept of a clear roadside. Also, these SI values were not in a form commonly used today, which is a scale of 1 to 10, with 10 being fatal. Instead, Glennon's results could exceed 10 if the percentage of fatalities and severe injuries was high.

Weaver, Post, and French began work on severity index estimation in 1975 [1]. Their approach would define severity indexes on a set scale from 0 to 10, with 10 representing a 100 percent fatality rate. They also recommended a definition for each severity on the scale that included the percent of PDO accidents, injury accidents, and fatal accidents. These definitions were based primarily on survey response in which participants were asked to rank objects by their severity. This allowed them to estimate severity indexes by examining accident reports for various roadside features. They gave estimated the severity index to be 3.0 on a roadside slope that was built up of sod. No distinction was made between slope steepnesses.

Zegeer and Parker worked to estimate the severity of utility poles [22]. Their work was significant in that it looked at fatal and injury accidents to indicate the severity of the object. In addition to this adjusted approach, they were able to conclude that the variability in the number of these extreme accidents was high from state to state.

McFarland and Rollins wanted to validate the definitions set forth by Weaver et al [23]. To do so, they examined 136,000 accidents between 1978 and 1979 in Texas. From their results, they concluded that in most cases, Weaver's recommendations were too high. However, for trees in particular, Weaver's recommendation was too low. Either way, it was shown that relying on survey responses is not a suitable way to determine accurate and reliable severity indexes.

Brogan and Hall conducted a study on fixed objects in New Mexico from 1980 to 1982 [24]. Their primary observation was that the magnitude of the severity index alone was not enough to describe the consequence of striking the object. The exposure of that object was also required. This would allow the researcher to estimate average annual accident costs by multiplying the cost of one accident, according to the severity scale and the associated severity costs, by the accident frequency for any given year.

In 1985, Mak began estimating the relative severity of object impacts based on the percent of fatal (K) and incapacitating injury (A) accidents ((K+A) accidents) [25]. The SI value was relative because the percent of (K+A) accidents at the target site was divided by the percent of (K+A) accidents at all sites. For the purposes of embankments, accident data taken from the National Accident Sampling System (NASS) was used, but no distinction between slope steepness was made. The use of (K+A) accidents to describe the severity of a feature was used in this roadside grading guidance paper because those types of crashes represented the majority of the societal costs associated with that feature. A fatal accident was estimated at $3.85 million and a severe injury accident was estimated at $226,600. The next highest societal cost (moderate injury or “B” accidents) was estimated at only $53,000. Therefore, the average severity was significantly affected by the K and A accident types.

The 1996 Roadside Design Guide makes use of a set of SI values for many slope and height combinations, as well as for several design speeds [26]. Those values were believed to be inaccurate in part because they were based on the design speed and not the impact speed. Because design speed was used, it was possible to get a positive value for an SI when the speed was zero, which is erroneous for any foreslope with a definable slope. RSAP utilizes these severity indexes, but the values were modified by passing a line through the origin and the SI values at each speed [6]. The square of the distance between that line and the SI values was minimized, resulting in a linear relationship between impact speed and the severity index.

Wolford and Sicking were able to establish a relationship between impact speed and SI values for varying steepnesses as well [27]. Their work examined approximately 13,700 accidents on embankments alone in the State of Michigan and even more in Utah between the years 1985 and 1992. They established representative foreslopes for rural interstates, rural arterials, and rural collectors, which had foreslopes of 4:1, 1V:3.5H, and 1V:2.5H, respectively. In addition, the average depth of these foreslopes was 6.6 ft (2.0 m). Using the percentage of each accident type on the KABCO scale, an average severity was calculated for each foreslope. From the results, additional severity relationships were extrapolated from the three known slope severities for depths of 6.6 ft (2.0 m). The results are compared to the default RSAP severity values and to the results of this report in Chapter 4.

The default version of RSAP (version 2003.04.01) used the severity indexes contained in the 1996 RDG, but those values were modified [6]. The modification was imposed to derive the severity index as a function of impact speed. The values listed in the RDG were based on the design speed. To adjust the SI values, a line as passed through the origin and through the SI values at each speed. The square of the distance between the line and each of the points was minimized. The result was a linear relationship between the impact speed and the SI, where an impact speed of zero would produce an SI of zero. The first step in determining new severity indexes would be to analyze accident reports filed by police officers. Police reports use a 5-level rating scale to describe accidents. This rating system is known as the KABCO scale, and its description is as follows:

- K – Fatal injury
- A – Severe or incapacitating injury
- B – Moderate or non-incapacitating injury
- C – Minor or possible injury, and
- O – Property Damage Only (PDO)

This 5-level scale was used to determine a severity index for any struck object. These indexes can range from 0 (no damages) to 10 (100 percent fatality rate). All indexes in between were comprised of some percentage of the 5-level scale used in accident reports; however, the injury levels (by percent) were determined by engineering judgment. The resulting breakdown of each severity index is shown in Table 2 and was taken from the 1996 RDG [26].

Table 2. Injury Level Percentages for Each Severity Index

Severity Index (SI)	Injury Level (%)						
	None	PDO1	PDO2	Minor Injury - C	Moderate Injury - B	Severe Injury - A	Fatal - K
0	100.0	-	-	-	-	-	-
0.5	-	100.0	-	-	-	-	-
1	-	66.7	23.7	7.3	2.3	-	-
2	-	-	71.0	22.0	7.0	-	-
3	-	-	43.0	34.0	21.0	1.0	1.0
4	-	-	30.0	30.0	32.0	5.0	3.0
5	-	-	15.0	22.0	45.0	10.0	8.0
6	-	-	7.0	16.0	39.0	20.0	18.0
7	-	-	2.0	10.0	28.0	30.0	30.0
8	-	-	-	4.0	19.0	27.0	50.0
9	-	-	-	-	7.0	18.0	75.0
10	-	-	-	-	-	-	100.0

The validity of these values may be questionable because they were also determined by survey responses. Recall, McFarland and Rollins showed that Weaver's results were incorrect, and Weaver's results used an injury percentage table very similar to that shown in Table 2. A possible reason for potential errors in these values was that most of the accidents included in the survey were biased towards higher speeds. As a result, the average severity indexes tend to be overestimated. This means that average accident costs will be over-estimated as well. For use in RSAP, the severity index for each feature is defined as a linear line between 0 and 60 mph (96.6 km/h). This gives a unit of increase in the SI per unit of increase in impact speed. The values used in this project are shown below. They were taken from the RSAP User's Manual [28].

Type No.	Description	SI at 0 mph	Rate of Slope	SI at 60 mph
Category 1 = Foreslopes				
7	6:1, H >=0.3 m (1 ft)	0.0	0.0286	1.72
9	4:1, H 0.3 m (1 ft)	0.0	0.0378	2.27
10	4:1, H >=2.0 m (7 ft)	0.0	0.0430	2.58
12	3:1, H 0.3 m (1 ft)	0.0	0.0458	2.75
13	3:1, H 2.0 m (7 ft)	0.0	0.0578	3.47
14	3:1, H 4.0 m (13 ft)	0.0	0.0597	3.58
19	2:1, H 0.3 m (1 ft)	0.0	0.0562	3.37
20	2:1, H 2.0 m (7 ft)	0.0	0.0778	4.67
21	2:1, H 4.0 m (13 ft)	0.0	0.0841	5.05

2.5 RSAP Input Values

Three categories of foreslopes have been defined by the American Association of State Highway Transportation Officials (AASHTO). They are recoverable, non-recoverable, and critical. A recoverable slope is defined by AASHTO in the RDG as a 1 Vertical (V):4 Horizontal (H) slope or flatter [2]. However, when dealing with a freeway or other arterials with wide roadsides, the designation in AASHTO's Geometric Design of Highways and Streets (Green Book) defines a recoverable slope as being flatter than 6:1 [29]. A motorist can safely and easily traverse this slope by slowing down or they can come to a stop.

A non-recoverable slope can be traversed. When vehicles encroach on these slopes, the vehicle is most likely to reach the toe of the slope and extend beyond that point. When a barn roof configuration is used, and the non-traversable slope is within the extent of lateral encroachment, clear zone widths must extend beyond the toe of the non-recoverable slope far enough to provide the driver with room to come to a safe stop. The RDG defines slopes between 3:1 and 4:1 as non-recoverable [2].

Critical slopes are likely to cause rollover, which is extremely hazardous even if seatbelts are used. Both the RDG and the Green Book define this category as 3:1 or steeper. When vehicles encroach on this slope, they are redirected more laterally, and as a result, they encroach much further beyond the edge of the travelway. To reduce the amount of lateral encroachment and save space in the clear zone width, a barrier is often warranted, provided the traffic volume is large enough to consider treatment. Figure 2 was created to determine when barriers are warranted, given slope conditions and average daily traffic (ADT) [2].

In addition to slope flattening, the use of a guardrail system was examined. There are two prevailing methods for determining the length-of-need of a guardrail system. The first is presented in the Roadside Design Guide (RDG) and is based on an encroachment frequency study conducted by Hutchinson and Kennedy [12]. However, this study was likely effected by the unfamiliarity of the motorists because the study was begun when the interstate it was conducted on was opened. This is supported by the fact that the number of low-angle encroachments was much larger in this study than in similar studies, which indicated the willingness of the motorist to pull over, which would be classified as a controlled encroachment, and not relevant to encroachment frequencies used in benefit-cost analyses. The large number of the low-angle encroachments erroneously increased the length of travel of the vehicle, which in turn erroneously increased the required length-of-need of the guardrail. In addition to the low-angle, controlled encroachments, evidence has recently been presented that shows Hutchinson's and Kennedy's data was affected by time trends and seasonal weather conditions [13]. Instead of a direct link between encroachment frequency and only ADT, the authors of this new study concluded that encroachment frequency was also a function of the weather conditions, with a higher frequency expected in the winter months.

The second method is presented in the NCHRP Report No. 638: Guidelines for Guardrail Implementation [30]. Like the RDG method, this method relies on encroachment frequency data to conduct a benefit-cost analysis. Unlike the RDG method, this method uses the Cooper encroachment frequency study [10]. This data indicated the same trend in the traffic volume as the Hutchinson and Kennedy data; however, this study was not influenced by driver unfamiliarity. Also, the length of low-angle encroachments was not as long as the corresponding length in the Hutchinson and Kennedy data. Because this length was shorter, the required runout length was shorter, as confirmed in studies done by Sicking, Wolford, and Coon [31-32].

RSAP depends on speed data collected by Mak before the national speed limit of 55 mph (88.5 km/h) was removed in favor of state-specified speed limits [6,33]. As a result, speeds above 55 mph (88.5 km/h) were not included. This was validated by work done by Albuquerque et al on impact conditions [34]. They concluded that the average impact speed was at most 45 mph (72.4 km/h), and that occurred only on Interstates.

In addition to providing an alternative method for calculating the length-of-need of a guardrail system, the NCHRP Report No. 638 can be helpful in determining values for other parameters, such as minimum slopes, maximum degrees of curvature, and maximum grades [30]. Also, offsets were determined from the minimum shoulder widths, assuming the worst-case scenario would place the slope at minimum distances from the edge of the shoulder. The report surveyed four states to determine minimum design standards for different functional classes. Those states were Iowa, Louisiana, New York, and Oregon. The results of that survey are shown in Table 3.

In addition to the roadside geometries, exposure information had to be included in the analysis. This information included the percent of trucks on the road, the expected traffic growth over the simulated design life, and the traffic volume in vehicles per day (vpd). All of this information was found on the Wisconsin Department of Transportation (WSDOT) webpage [35]. The percent of trucks on Interstate-90 was 16 percent. Additionally, the traffic growth percentage between 2010 and 2020 was 2.1 percent. Finally, traffic volumes were estimated for each functional class. These values ranged from 100 vpd (rural local) to over 90,000 vpd (freeway).

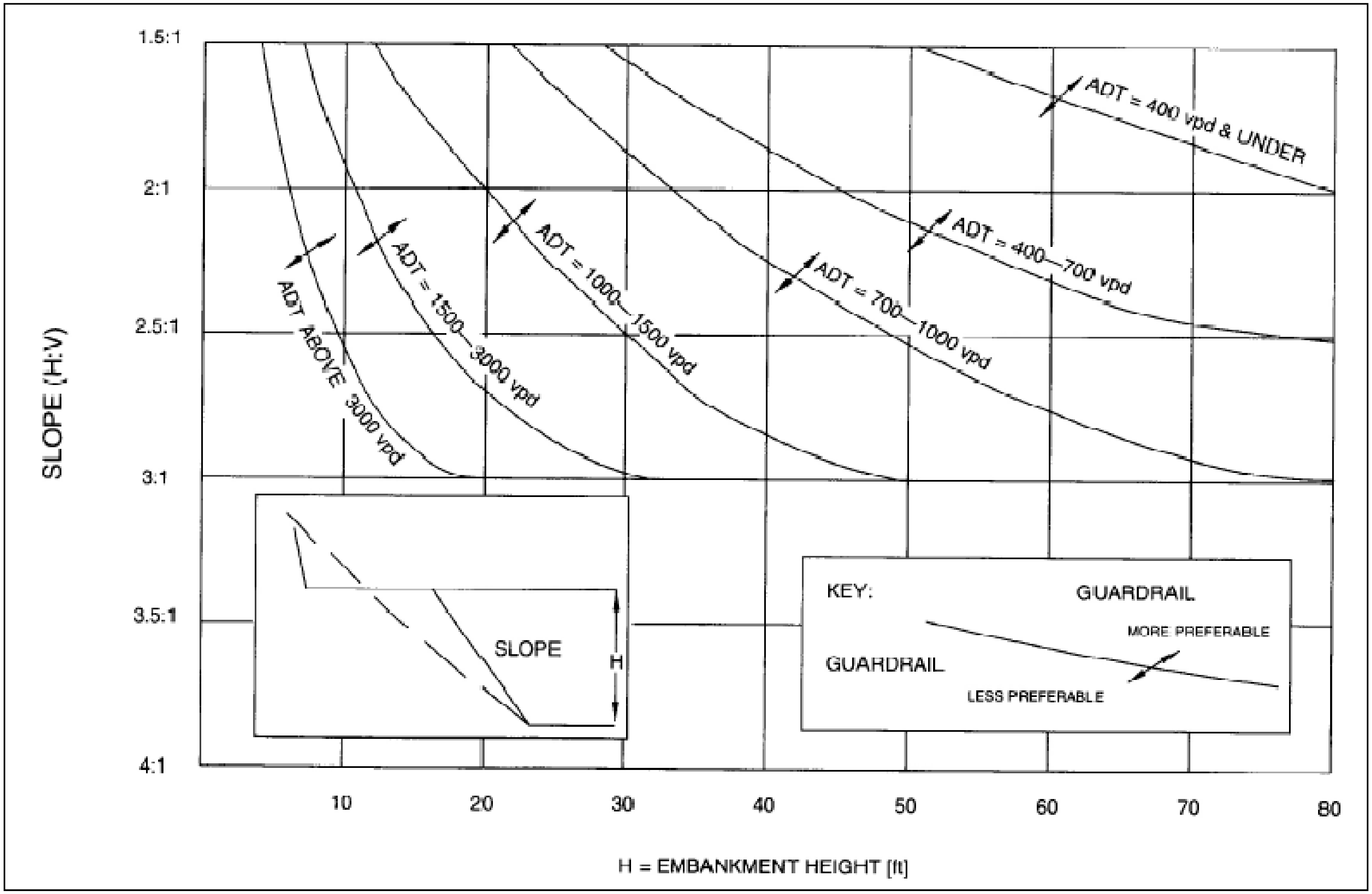


Figure 2. Design Chart for Embankment Warrants Based on Fill Height, Slope, and ADT [2]

Table 3. Minimum Design Standards

Characteristics	**Rural Local/ Collector**	**Rural Arterial**	**Urban Local/ Collector**	**Urban Arterial**	**Freeway**
Min. Shoulder Width, ft (m)	2 - 8 (0.6 – 2.4)	4 – 8 (1.2 – 2.4)	6 – 8 (1.8 – 2.4)	6 – 10 (1.8 – 3.0)	8 – 12 (2.4 – 3.7)
Min. Clear Zone, ft (m)	7 – 17 (2.1 – 5.2)	6 – 26 (1.8 – 7.9)	8 – 26 (2.4 – 7.9)	9 – 38 (2.7 – 11.6)	10 – 38 (3.0 – 11.6)
Max. Side Slope	2:1 – 6:1	3:1 – 6:1	3:1 – 4:1	3:1 – 6:1	3:1 – 6:1
Max. Horizontal Curvature (degrees)	5 – 8	3 – 6	7 – 37.5	5 – 10	2 – 3
Max. Grade (percent)	4 – 10	3 – 6	7 – 12	5 – 9	3 – 5

2.6 Accident Costs and Direct Costs

Once the severity of the accident is known, the accident cost can be determined. To do so, each severity index was assigned to a cost, based on the 1994 gross domestic product per capita. The societal cost, according to the FHWA, was $2.6 million per fatality in 1994, but that value has been increased for this project by using the Gross Domestic Product implicit price deflator [36]. Based on the trending price deflator, in 2014, the cost of a fatality will be approximately $3,850,942. Based on this cost, the remaining costs for each SI were determined using the percent of injury levels shown in Table 2. Those costs are shown in Table 4.

The accident costs shown in Table 4 represent baseline accident costs in RSAP. It is then modified by multiplying it by the probability of injury. For example, the probability of a fatality is so small, that the cost of an SI = 10 would be considerably less than $3.85 million. This new cost is known as the unadjusted accident cost. It is then adjusted again using four weighting factors. Those factors are associated with the encroachment speed and angle, vehicle orientation, vehicle type, and the lane of departure of the encroachment. The result is the weighted accident cost. Next, the cost is related to the distance from the edge of the traveled way to the object. As the object's distance increases, the probability of striking it also decreases. Therefore, the weighted accident cost is multiplied by the probability of striking the object at the given offset. The result is the encroachment accident cost. Finally, the sum of the encroachment accident costs is divided by the number of modeled encroachments for each convergence check to give the average encroachment cost.

Table 4. Societal Costs for Each Severity Index

Severity Index (SI)	Accident Cost
0	$ -
0.5	$ 2,962
1	$ 5,958
2	$ 12,027
3	$ 63,215
4	$ 155,252
5	$ 365,366
6	$ 771,996
7	$ 1,253,067
8	$ 2,008,711
9	$ 2,939,928
10	$ 3,850,942

3 RESEARCH APPROACH

An accident report database from the State of Ohio in the year 2000 was used in an attempt to understand the correlation between roadside geometries and accident severities. From this data, a more accurate subset of severity indexes was created and integrated into RSAP. A test matrix was constructed to adequately cover possible roadway configurations, and these configurations were analyzed by RSAP. The results from this analysis were used to determine the coefficients of linear equations that could be used to calculate the accident cost as a function of the average daily traffic (ADT). The first step was to determine accurate severity indexes for foreslopes. A severity index is a number from zero to ten used to estimate the societal cost in the form of property damages, injuries, and fatalities or a combination of the three.

Current severity indexes are overestimated because the surveys that were used to determine them were representative of high-speed impacts [6]. As a result, the benefit of improved safety features would be underestimated. This benefit would be observed in the form of reduced societal costs. Therefore, the severity indexes must be updated to accurately reflect damages associated with impacts with roadside slopes. This was done using data taken from the Highway Safety Information System (HSIS) for Ohio. This data included accident locations, highway names and classifications (such as State Route, US route, or Interstate), county name, number of vehicles involved in the accident, accident location (on or off the road), number of passengers, accident severities (on a 1-5 scale, with 1 being fatal), first harmful event, and most harmful event. From this database, the accidents were sorted to include single-vehicle, ran-off-road accidents where no fixed objects were struck, and the most harmful event was an impact with a slope or embankment. To do so, the HSIS Guidebook for the Ohio State Data Files was used [37].

In addition to the accident data provided in the HSIS files, cross-sectional measures were taken using the Ohio Geographically Referenced Information Program (OGRIP) and a topographical tool called Global Mapper. The OGRIP included Light Detection and Ranging (LiDAR) files for 25,000 square foot (2,322.6 square-meter) tiles. These tiles could be read by Global Mapper and used to measure three-dimensional features, such as the slope and height of the embankment. The results of these measurements were combined with the HSIS database of accidents to begin to establish a link between accident severities and the roadside geometries.

Slopes can be classified by their steepness. They are described in terms of the ratio of the vertical distance to the horizontal distance. Flat slopes typically have one unit of vertical distance to every six units of horizontal distance (6:1), whereas steep slopes are typically steeper than 3:1. The results of a preliminary analysis indicated that the severity of the flatter slopes was the same as the severity of the steeper slopes; however, intuition would suggest otherwise. This can be explained by the fact that less severe accidents (which occur mostly on flatter slopes) were not reported. If they had been, the average severity of the flatter slopes would have been reduced. To account for the missing accidents, the number of severe or fatal accidents on each slope category was used to adjust the severity calculations in RSAP. This was done by assuming a linear relationship between the number of these extreme accidents and the mileage of each slope category. These slope categories were ranges of slopes derived from the slope classifications of recoverable, nonrecoverable, and critical, as defined in the Roadside Design Guide [2]. A recoverable slope allows the motorist to maintain control of vehicle and even return it to the roadway safely. They have slopes flatter than 4:1. A non-recoverable slope allows the motorist to maintain some measure of control in the form of maneuvering and slowing down, but it prevents the motorist from returning to the roadway. They have slopes flatter than 3:1 but steeper than 4:1. A critical slope forces the motorist to reach the toe of the slope and encroach beyond that point. They have slopes steeper than 3:1.

Using trial-and-error, the severity index modification factor used by RSAP was modified until the number of severe or fatal accidents predicted by RSAP matched the accident data found in the HSIS files. Once the severity indexes were corrected, roadside configurations were developed and programmed into RSAP. A test matrix was established representing a wide spectrum of possible scenarios. RSAP was allowed to run continuously until all the scenarios were simulated. The results were tabulated and used to develop that can be used to predict the accident cost directly from the applicable ADT value. The coefficients for these equations are presented in this report, but in addition, a Microsoft Excel spreadsheet was created that automatically calculates an accident cost for any ADT and scenario. This calculation included linear interpolation between two known accident costs at known parameter inputs and linear extrapolation beyond the range of known values.

4 SEVERITY INDEXES FOR FORESLOPES

4.1 Problem

Attempts to estimate severity indexes (SIs) have been made for many different roadside features, including foreslopes. One prevailing method used to estimate these indexes was to survey highway safety officials about accidents in which those officials were asked to rank the severity of accidents on a scale of 1 to 10. Those responses are believed to have been biased towards high-speed accidents, and as a result, the average severity indexes were overestimated [6]. In order to conduct an accurate benefit-cost analysis on the effect of flattening slopes, these SI values needed to be updated because they have the single largest influence on the accident cost of a given scenario. For example, a change in severity index from 2.52 to 3.23 (a 28.2 percent increase) resulted in a change in accident cost from $38,644.50 to $84,383.90 (a 118.4 percent increase). This problem gave rise to a set of objectives that were partially separate from the original objectives of the report.

4.2 Objective

First, new SI values needed to be developed and based on actual accident data, as opposed to the opinions of safety officials. This objective would not only be necessary for the completion of this report, but it may also be useful in other benefit-cost analyses involving roadside foreslopes.

Second, the new SI values needed to be implemented into the benefit-cost analysis tool, RSAP, to produce more accurate accident costs, which can be used to determine the cost-effectiveness of flattening a slope.

4.3 Accident Data Description and Analysis

4.3.1 Data Description and Preliminary Analysis

Accident data collected by law enforcement officials in the state of Ohio in the year 2000 was used to estimate new severity indexes for foreslopes. That accident data was recorded in the Highway Safety Information System (HSIS). The original data population included 17,948 accidents. These accidents were then filtered to include only single-vehicle, ran-off-road (SVROR) accidents where no fixed object was struck and an embankment or ditch impact was included in at least one impact event. This reduced the number of accidents to 1,294. Each accident was assigned a severity value on a scale of 1 to 5 with 1 being fatal (K) and 5 being a property-damage-only (PDO) accident (O). The location of the accident was also included and was used to find the site on a digital map located on the Ohio Geographically Referenced Imagery Program (OGRIP) [38]. This program included 25,000 square-foot (2,322.6 square-meter) LiDAR tiles that could be downloaded and used to view that area in a 3-dimensional topographical format. The State of Ohio also provided data pertaining to the location of highways and county lines in the form of graphical layers. These LiDAR tiles and layers were then combined in a program called Global Mapper. This program was capable of examining cross-sections of the LiDAR tiles, which provided a view of the slope and tools to measure that slope as well as the height of the roadway above the base of the slope. Based on the location given in the HSIS data and the highway and county lines given in the layers, the locations of the accidents were determined in Global Mapper, at which point, the slopes and heights at each accident location were measured and recorded.

When combining the results of the accident data severities and the cross-sectional measurements, the number of (K+A) accidents per mile per slope-height category could be estimated. To do this, each accident was sorted into one of nine categories. Those categories were developed by combining the slope with the height. Four slopes were chosen to be consistent with RSAP: (i) 2:1 for critical slopes; (ii) 3:1 for non-recoverable slopes; (iii) 4:1 for recoverable slopes; and (iv) 6:1, also for recoverable slopes. Three height categories were chosen as well. Short heights were considered less than 4 ft (1.2 m) tall. Medium heights were considered greater than or equal to 4 ft (1.2 m) but less than 10 ft (3.0 m) tall, and tall slopes were considered greater than or equal to 10 ft (3.0 m) tall. The 2:1 and 3:1 slopes utilized all three height categories, creating six combinations. The medium and tall heights were combined into one category and used with the short height category for the 4:1 slope, creating two combinations. Finally, all three height combinations were combined into one category and used with the 6:1 slope to create the ninth and final combination. These slope-height combinations were chosen to be consistent with the slope-height combinations currently used in RSAP and are illustrated in Table 5.

Table 5. Slope-Height Combinations

Height, ft (m) Slope	$h < 4$ (1.2)	4 (1.2) $\leq h <$ 10 (3.0)	$h \geq 10$ (3.0)
1V:2H	I	II	III
1V:3H	IV	V	VI
1V:4H	VII	VIII	
1V:6H	IX		

The preliminary results suggested that the severity of a non-recoverable slope was approximately the same as the severity of a recoverable slope. Obviously, as the slope steepness increases, the severity should also increase. The discrepancy in this logic can be explained by unreported accidents. Impacts or encroachments on slopes can result in one of four outcomes: (1) the vehicle may return to the roadway without incident; (2) the vehicle may come to a controlled stop; (3) the vehicle may strike some fixed object on or beyond the slope; or (4) the vehicle may rollover [27]. The third possibility was eliminated in this study by filtering out all accidents in which a fixed object was struck. The remaining three were left to influence the severity of the slope; however, the first two possibilities often result in little or no damage. After one of these accidents, the motorist was unlikely to report the accident to authorities. These unreported accidents would have occurred more often on flatter slopes. If they had been reported, the increased number of low-severity accidents would have increased the overall mileage of accidents for each slope category, effectively reducing the number of (K+A) accidents per mile on the recoverable slopes. Instead, the number of (K+A) accidents for recoverable and non-recoverable slopes was within 22 percent of each other whereas the difference between a critical and non-recoverable slope was 41 percent. These results are shown in Table 6. The lengths used in this table were the lengths provided in the accident data. Each accident was given a segment length over which the accident occurred. For filtering purposes, the critical slope range was defined as slopes steeper than 1V:2.5H, and the recoverable slope range was defined as slopes flatter than 1V:3.5H. All slopes between these limits were classified as non-recoverable.

Table 6. Severity Calculations Based Only on Accident Data

Slope Category	Slope Range	#(K+A)	Length, miles (km)	#(K+A)/mile ((#K+A)/km)
Critical	< 2.5H	19	865.0 (1,392.0)	0.02197 (0.01365)
Nonrecoverable	2.5H to 3.5H	7	449.9 (724.1)	0.01556 (0.00097)
Recoverable	> 3.5H	27	2110.6 (3,396.7)	0.01279 (0.00795)

It was believed that the number of miles per slope category was under-represented for recoverable slopes and possibly non-recoverable slopes due to unreported accidents with relatively low severity levels. This length was intended to be a total length for the entire highway system in the State, but due the limited sample size, many locations throughout the state were not represented in the accident data. In order to more accurately assess the number of (K+A) accidents per mile per slope type, the number of miles of each slope type had to be estimated across the State of Ohio.

4.3.2 Mileage of Slope-Height Combinations

To determine a more representative mileage for each slope category, the entire highway network in Ohio should be examined. The State of Ohio has 12,776 miles (20,561 km) of rural, two-lane highways [37]. In order to determine how those miles are divided up into the slope categories, discretized segments were measured using LiDAR tiles and Global Mapper. This was necessary to determine the slopes and heights of every segment along the highways. These segments would have to be small enough that significant changes in the slope would not be prevalent in one segment. For this report, 100-ft (30.5 m) long segments were used. This would require approximately 677,128 measurements to determine exactly how many miles of each slope type there are on rural, two-lane highways. By assuming conservatively that each measurement takes one minute, it should be obvious that the time demand would be too enormous to consider this approach. Instead, highway segments were taken at random and were assumed to represent the total highway network. From these random samples, the percentage of each slope type could be determined and applied to the total highway length to estimate the mileage for each slope type in Ohio.

In order to model the statewide highway network, 150 segments of rural highways were randomly selected. This was accomplished by using roadway description inventory reports, such as the one shown in Appendix A. These tables were imported into Microsoft Excel, where filters were applied to the data to eliminate urban segments. In addition, interstate highways were filtered out, leaving behind U.S. and State routes. These highway types were considered because they are similar to typical rural, two-lane highways, which make up the vast majority of the total mileage in Ohio. Once the data was filtered, the total length was 11,393 miles (18,335 km). The difference in this value and the total number of rural, two-lane highway miles was due to the overlapping of some highways. The longer length included some stretches of highways twice because they had two names. The filtered data eliminated repeated data, leaving behind the total number of actual miles.

Once the filtered data was prepared, the highways were placed end-on-end by summing a cumulative length from the first highway segment to the last. Then a random number was generated between 0 and 11,393. This number was used to select a highway. This process allowed the longer highways to be selected at a greater probability, which allowed the random samples to more accurately model the actual highway distribution. This was imperative because accidents were more likely to occur on long highways than short highways due to the increased exposure. Each data entry from the inventory report broke the highway into segments, using landmarks or some other distinguishing features to describe each of those segments. The previously generated random number was also used to select a segment within the highway. However, once the segment was chosen, a new random number had to be generated to determine the starting point for measurements in Global Mapper. As previously mentioned, 100-ft (30.5-m) sub-segments were used for each segment. Those segments measured just over 1 mile in length or 5,300 ft (1615.4 m). As a result, a random number was generated between the beginning milepost of the segment and 1 mile (1.61 km) less than the ending milepost for that segment to determine a starting milepost. This ensured that the entire 1-mile (1.61-km) segment would be located in the selected highway. Once those 150 segments were chosen, they were investigated using Google Maps to see if they were in fact rural, two-lane highways. If they did not meet these criteria, they were ignored. Of the 150 segments, 127 were used. The used segments were measured the same way the accident data were measured.

Using Global Mapper and the OGRIP database, slope and height measurements were taken along both sides of the highway. This was done because the location of the accidents was unknown. The side of the road the accident occurred on was given in the accident database, but the relative direction of the vehicle prior to the accident was not given. As a result, the encroached side of the roadway could not be ascertained. Also, by using both sides of the highway, the sample size was doubled to 254 miles (408.8 km).

To determine if the samples were an adequate model for the entire highway system, the ratio of State to US routes was compared for the 11,393 miles (18,335 km) and for the 127 miles (204.4 km). Those ratios were 3.34 and 3.10, respectively. This constituted a difference of only 8 percent, and as a result, the samples were considered to be an adequate model.

In addition to determining mileage for each slope category, the mileage for each height category had to be determined. As previously mentioned, each slope category was broken into height categories. The critical and non-recoverable slopes used three heights: short or less than 4 ft (1.2 m), medium or greater than or equal to 4 ft (1.2 m) but less than 10 ft (3.0), and tall or greater than or equal to 10 ft (3.0 m). The recoverable slopes were broken into two slope categories: 4:1 and 6:1. For the 4:1 slope, two heights were used because the medium and tall heights were combined. For 6:1 slope, all height categories were combined. Finally, to determine the number of miles in each of these nine combinations, the number of miles for the slope-height combination was divided by 254 (the total miles of the sample). This fraction was applied to the total mileage, 11,393 miles (18,335 km), to determine the number of expected miles in each slope-height combination. The results of the estimated mileage are shown in Table 7. To contrast the difference from the previous severity calculations as summarized in Table 6, the recoverable miles increased by 340 percent.

Table 7. Severity Calculations Based on Estimated Mileage

Slope Category	Slope Range	#(K+A)	Length, miles (km)	#(K+A)/mile ((#K+A)/km)
Critical	< 2.5H	19	815.4 (1,312.3)	0.0233 (0.01448)
Nonrecoverable	2.5H to 3.5H	7	1096.5 (1,764.6)	0.00638 (0.00397)
Recoverable	> 3.5H	27	9264.0 (14,909.0)	0.00291 (0.00181)

The recoverable slope was treated differently than the other two slope categories, because it was represented by two slopes. As a result, the total mileage for those two slopes had to be estimated. From the accident data, 38.6 percent of the accidents on recoverable slopes occurred on slopes steeper than 1V:5H, or halfway between 4:1 and 6:1. Then, once the miles of recoverable slopes was multiplied by 0.386, it was then broken further into the height categories to give the mileage for the 4:1 slope. The 6:1 slope mileage was simply 61.4 percent of the total recoverable slope mileage. Using the number of (K+A) accidents determined from the accident data, the number of (K+A) accidents per mile could be estimated for each slope-height combination. These results are shown in Table 8 in US units and Table 9 in SI units.

Table 8. #(K+A) per Mile for Each Slope-Height Combination

Height	Slope											
	1V:6H			1V:4H			1V:3H			1V:2H		
	Length	# (K+A)	#(K+A)/ mile	Length	# (K+A)	#(K+A)/ mile	Length	# (K+A)	#(K+A)/ mile	Length	# (K+A)	#(K+A)/ mile
Short	5688	18	0.0032	2521	2	0.0008	260.1	0	0.0000	235.5	6	0.0255
Medium				1055	7	0.0066	606.9	2	0.0033	175.5	6	0.0342
Tall							229.5	5	0.0218	404.4	7	0.0173

Table 9. #(K+A) per Kilometer for Each Slope-Height Combination

Height	Slope											
	1V:6H			1V:4H			1V:3H			1V:2H		
	Length	# (K+A)	#(K+A)/ mile	Length	# (K+A)	#(K+A)/ mile	Length	# (K+A)	#(K+A)/ mile	Length	# (K+A)	#(K+A)/ mile
Short	9154	18	0.0020	4057	2	0.0005	418.6	0	0.0000	379	6	0.0158
Medium				1698	7	0.0041	976.8	2	0.0020	282.5	6	0.0212
Tall							369.4	5	0.0135	650.8	7	0.0108

4.3.3 Calculation of New Severity Indexes

4.3.3.1 Approach

RSAP utilizes a linear relationship between impact speed and severity. This relationship was used in this report to determine new SI values for foreslopes based solely on the number of (K+A) accidents per mile. The results from taking measurements with Global Mapper and combining the measurements with the accident data were presented in the previous section; however, those results were inconsistent at times owing to the small sample size. As a result, the results had to be modified to produce useable accident rates per mile per slope-height combination. Once that was accomplished, the RSAP SI modification factor was modified by trial-and-error until the simulated number of (K+A) accidents closely matched the modified accident data results. Once those values matched, a new average SI was calculated by RSAP.

4.3.3.2 Results

The results of the determination of the number of (K+A) accidents per mile was shown in Table 8, but it had to be modified to account for unexpected discrepancies in the data. For example, the number of (K+A) accidents per mile decreased for the 2:1 slope from the medium height to the tall height. It is common knowledge that as the height increases, the severity increases as well. The discrepancy was caused by the small sample size. It is expected that as the number of accidents in the database increases by including additional years of data, the number of (K+A) accidents for tall heights would increase relative to the medium heights. An example of the problem of tall heights is shown in Figure 3.

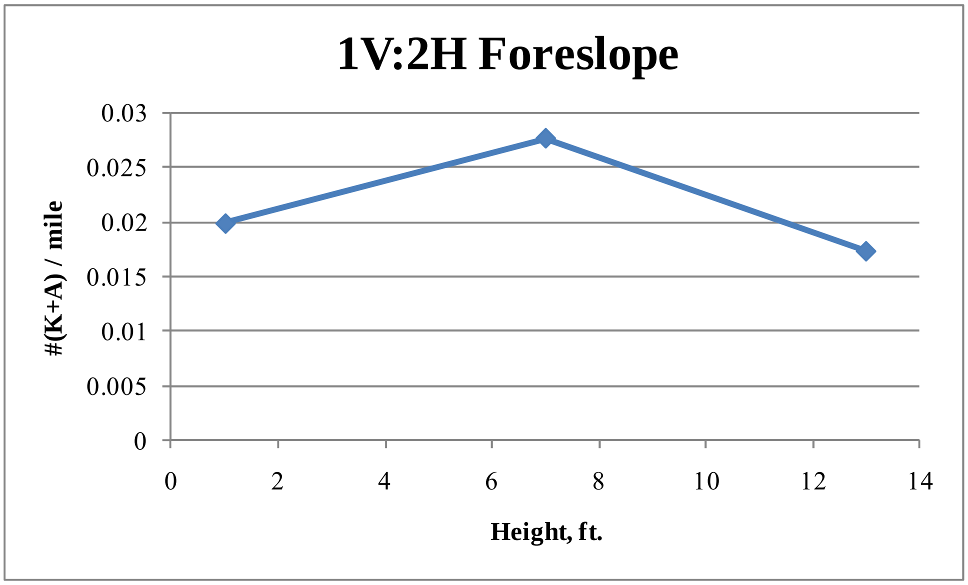


Figure 3. Accident Rate for 2:1 Slope, Demonstrating Unreliability of Tall Heights

In addition to the height complication, the number of (K+A) accidents decreased from recoverable slopes to non-recoverable slopes. This was because non-recoverable slopes represent a significantly smaller sample of the total mileage of slope steepness. The recoverable slopes flatter than 6:1 were by far the most common slope type, and because of the increased exposure, were sure to have more accidents of all types. As a result, a monotonically increasing “best-fit” line was passed through the plots of the number of (K+A) accidents verses the slope steepness. This was accomplished by using a logarithmic function as shown in Figure 4. This procedure was applied to short and medium heights but was neglected for tall heights due to the trend shown in Figure 3.

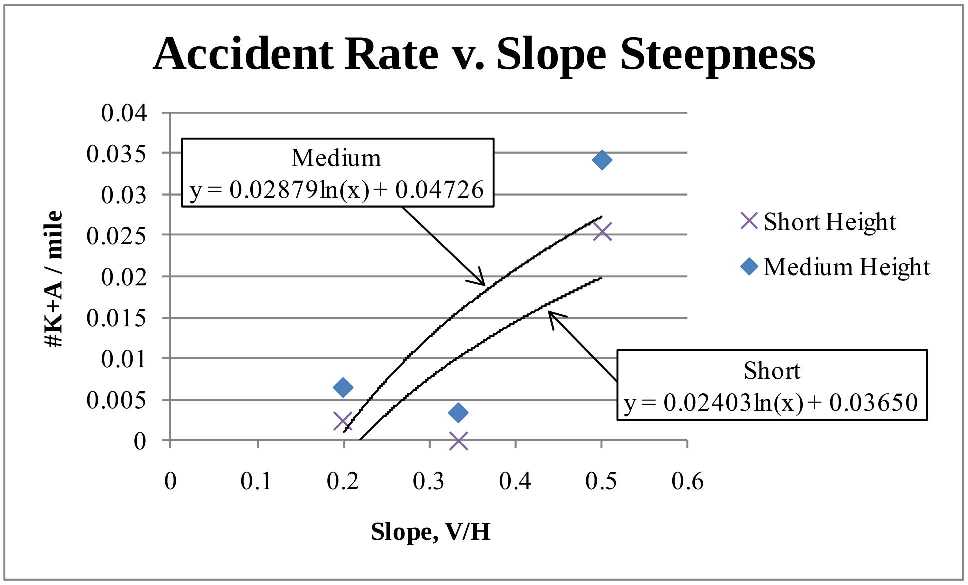


Figure 4. Accident Rate vs. Slope Steepness for Short and Medium Heights

From the logarithmic functions, linear equations were developed by solving for the number of (K+A) accidents for each slope for both the short and medium heights. It was assumed that the short height was 1 ft (0.0.3 m) and the medium height was 7 ft (2.1 m). This gave two points for each slope, which were then used to construct the slope-intercept equations shown in Equations 2 through 4. These equations were used to determine the number of (K+A) accidents per mile for each slope and height combination, including the tall heights.

$$\varphi_2 = 0.00130h + .01854 \quad (2)$$

$$\varphi_3 = 0.00098h + .00912 \quad (3)$$

$$\varphi_4 = 0.00021h - .00021 \quad (4)$$

Where φ_2, φ_3, and φ_4 are the number of (K+A) accidents per mile for the 2:1, 3:1, and 4:1 slopes respectively, and *h* is the height of the foreslope in feet. The expected number of (K+A) accidents per mile for the 6:1 slope was reduced to zero since there were no accidents on heights less than 13 ft (4.0 m). It should be noted that at 1 ft (0.3 m) the number of (K+A) accidents on a 4:1 slope goes to zero. The reductions on the recoverable slopes may be overestimated, but this overestimation would be conservative because it would reduce the severity of flat slopes in comparison to steeper slopes or guardrail applications, making the flat slopes better alternatives than if default SI values were used. If more data becomes available, the results for the 4:1 and 6:1 slope should be revisited. The graphical results of Equations 2 through 4 are shown in Figure 5.

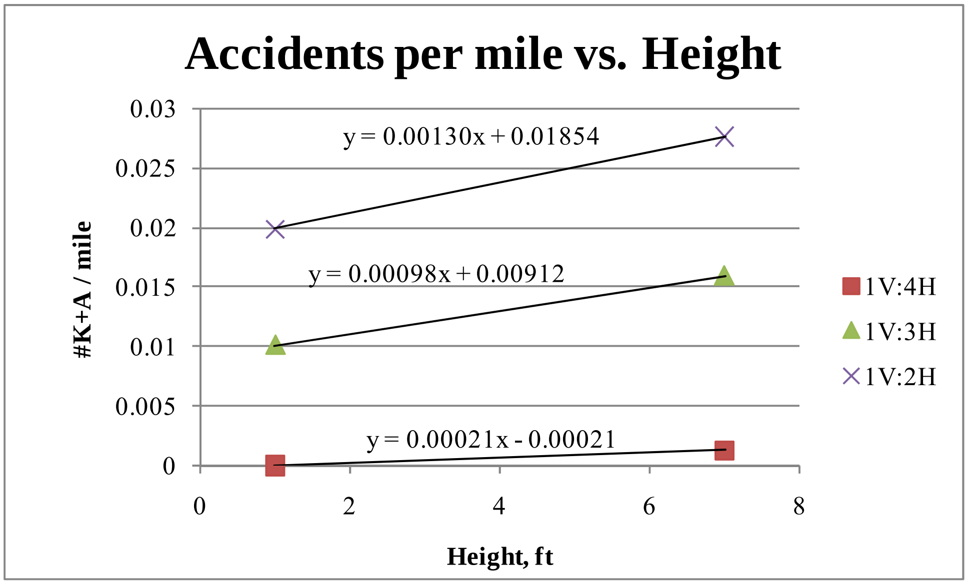


Figure 5. Accident Rates for Foreslopes

Once the expected number of fatal or severe accidents was known, the trial-and-error process was begun that would alter the simulated number of (K+A) accidents. As a stochastic program, RSAP looks to outside data files for some of its input. One of those files contains information for only foreslopes. In that file, there is a severity index modification factor, which by default, is set to one. By reducing this value, the number of simulated (K+A) accidents would also be reduced, which was required based on the default simulation results and the accident data results. Because of the inexact nature of the Monte Carlo technique, the precision of this factor was carried out to two decimal places. When two adjacent factors (say 0.62 and 0.63) straddled the expected number of (K+A) accidents, the value that yielded the closest result was chosen. This process was repeated for each of the slope-height combinations. The results of this process, including the new SI values, are shown in Table 10, assuming the traffic volume was 10,000 vpd on a rural principal arterial, undivided highway with a speed limit of 55 mph (88.5 km/h).

Table 10. SI Values and Modification Factors with #K+A Results

Slope	Height (ft)	Default RSAP SI	Default RSAP #K+A per mile	SI Modification Factor	New RSAP SI	DATA #K+A per mile	New RSAP #K+A per mile
1V:6H	Any	1.65	0.00469	0.60	0.98	0.0000	0.0000
1V:4H	1	2.18	0.01597	0.46	1.00	0.0000	0.0000
	7 & 13	2.47	0.02548	0.53	1.31	0.0013	0.0013
1V:3H	1	2.64	0.03458	0.75	1.97	0.0101	0.0102
	7	3.34	0.08077	0.65	2.17	0.0160	0.0157
	13	3.45	0.08987	0.69	2.37	0.0219	0.0218
1V:2H	1	3.24	0.07234	0.71	2.30	0.0198	0.0197
	7	4.48	0.17235	0.56	2.51	0.0276	0.0268
	13	4.84	0.19787	0.55	2.66	0.0354	0.0355

Comparatively speaking, these results were less than the results presented by Wolford and the default values of RSAP. This was expected, considering the RSAP results were possibly biased toward higher-speed accidents. For an illustrative comparison of the three sources of SI values, see Figures 6 and 7. These plots were created assuming the embankment height was 7 ft (2.1 m).

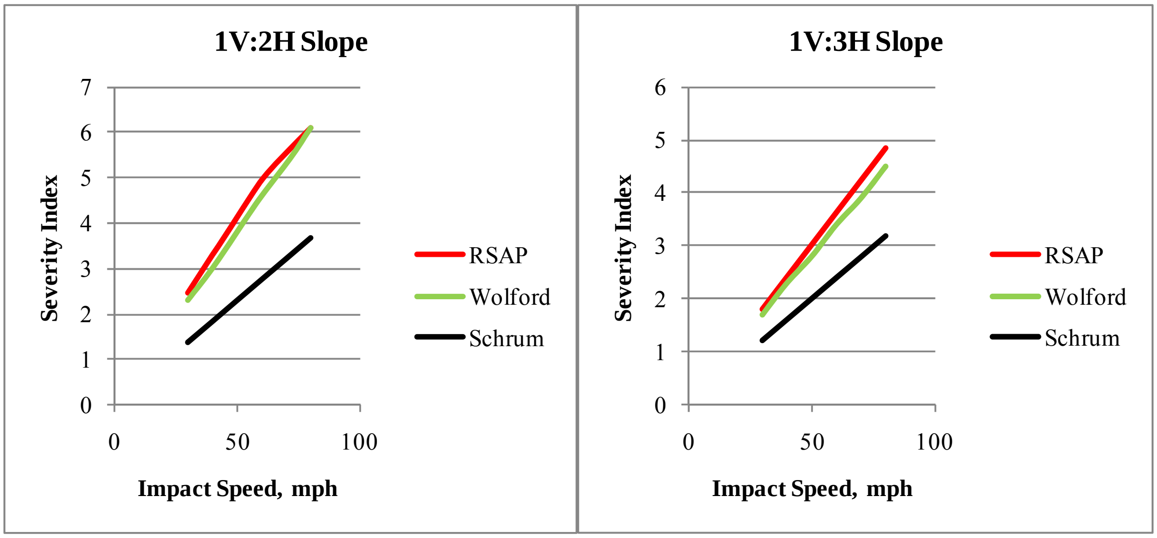


Figure 6. Severity Indexes - 2:1 and 3:1 Foreslopes

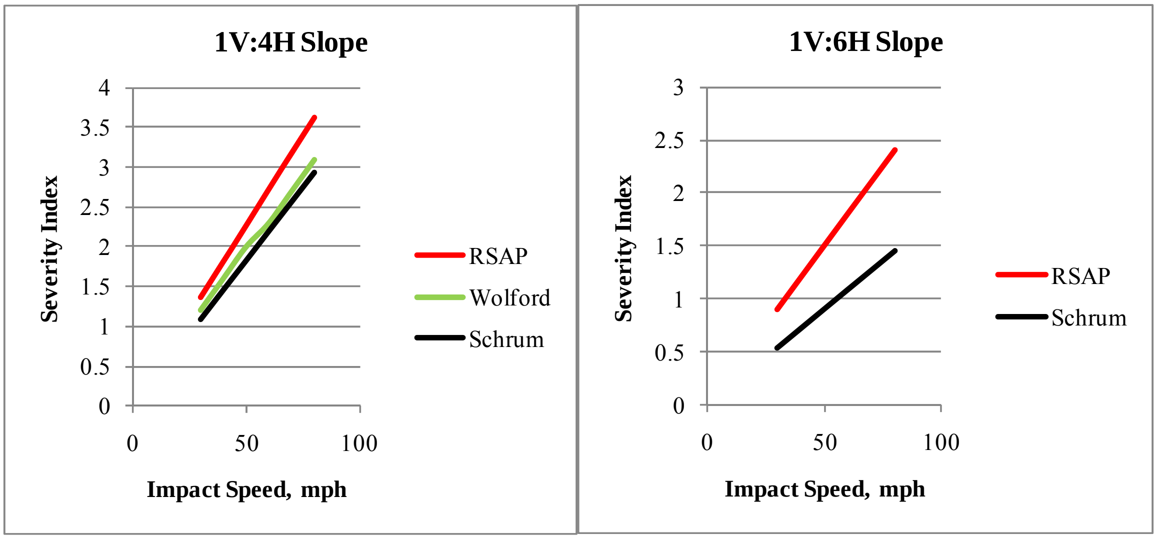


Figure 7. Severity Indexes - 4:1 and 6:1 Foreslopes

5 SENSITIVITY ANALYSIS

5.1 Analyzed Parameters

Eighteen parameters were evaluated against the baseline condition (shown in Figure 8) to observe the impact of each parameter. The impact of each parameter was converted into a sensitivity index and was used to establish a more refined pool of parameters to vary in the detailed study.

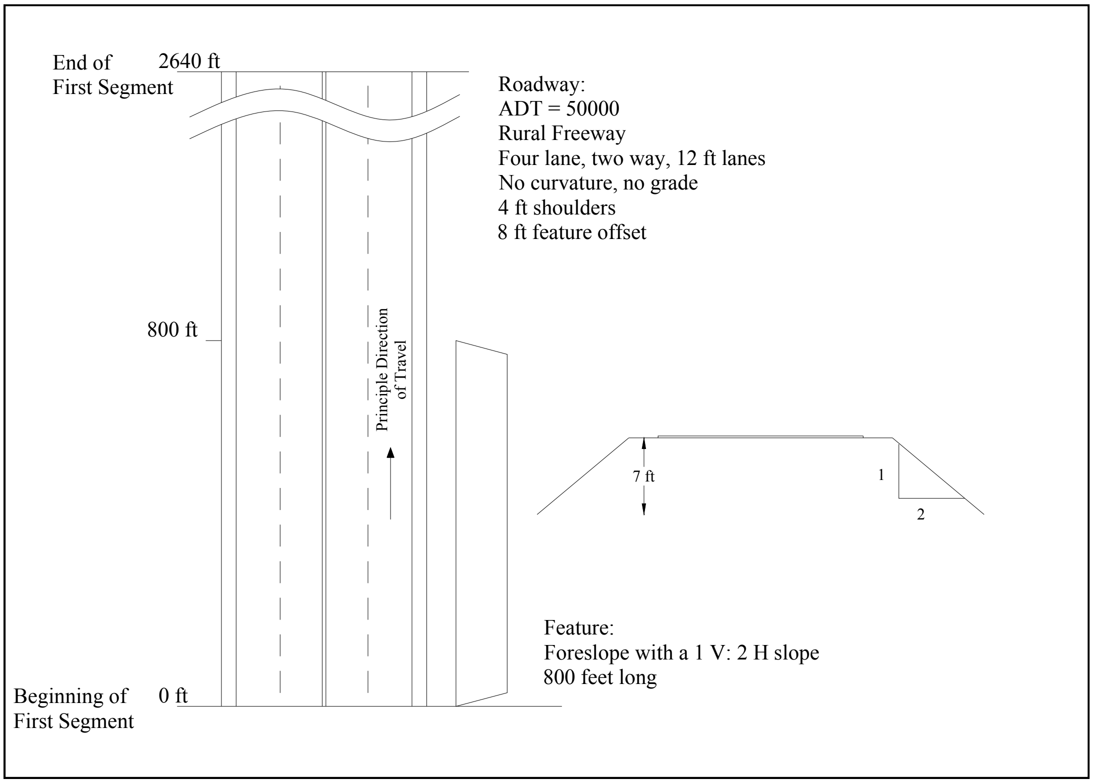


Figure 8. Base Condition for Sensitivity Analysis

The median width was chosen from the barrier warrant diagram given in the Roadside Design Guide [2]. An average width of 40 ft (12.2 m), or midway between 30 ft (9.1 m) and 50 ft (15.2 m), was chosen. Because this report considers the use of a longitudinal barrier, this barrier warrant was justified. The number of lanes was tested to cover a range of 2 to 6 lanes, which is adequate when dealing with rural local and arterial highways as well as rural freeways. The volume of traffic was varied from 10,000 to 90,000, which, with the exception of local highways, reflects most highway conditions. The degree of curvature was of particular concern, and as a result, the analysis was conducted on an extreme range of possible curvatures. Similarly, the grade of the highway was adjusted to show the impact of both downgrades and upgrades.

All functional classes were analyzed, and it was determined that each had particular impacts on the study. Likewise, the area type (rural or urban) was shown to influence the accident costs, but on a smaller scale. The functional classes and area types were combined in RSAP and were treated as one parameter in the detailed study.

The level of service of a highway represents operating conditions at or near the highway's capacity and are described on an alphabetical scale from “A” to “F,” with the latter representing a complete breakdown in flow [39]. The level of service traffic volumes were used to select standard lane and shoulder widths. Typically, lanes are 12 ft (3.7 m) wide. Reducing that width reduces the highway's service volume for a level of service of “E” by 13 percent for a width of 10 ft (3.0 m) and 24 percent for a width of 9 ft (2.7 m) [40]. As a result, the parameter study only accounted for a reduced width of 10 ft (3.0 m). To analyze larger widths with the same degree of change, the upper range was represented by a 14-ft (4.3-m) width. Shoulder width was included in this analysis but had little impact and, ultimately, was dropped from consideration. Shoulder widths larger than 6 ft (1.8 m) had no added benefit to service volume, while 2-ft (0.6-m) widths only reduced the capacity service volume by 7 percent at a level of service of “E” and a 12-ft (3.7-m) lane width [40].

The traffic growth rate and percent of trucks were estimated by the Wisconsin Department of Transportation (WSDOT) to be approximately 2 percent and 16 percent, respectively [35]. To verify that these parameters could be held as constants, they were analyzed as part of the sensitivity analysis and were found to be inconsequential.

The distance from the edge of the travel way to the obstruction, or offset, was also analyzed. Values for this parameter were small by comparison to the RDG recommendations for clear zone distances, which can approach 28 ft (8.5 m) on foreslopes [2]. However, in urban areas, no actual requirements are given. A study by the Iowa State University presented results from a survey that indicated a desirable offset of 12 ft (3.7 m) was common in many states [41]. As a result, a 12-ft (3.7-m) offset was chosen as the maximum offset, with 4-ft (1.2-m) increments, making 8 ft (2.4 m) the baseline offset.

For the sake of completeness, the different alternatives and heights were considered in the sensitivity study. The heights were chosen to represent a range of severities. At 1 ft (0.3 m), the severity of a 2:1 foreslope at 62 mph (100 km/h) was 3.1 on smooth and firm conditions, according to the 1996 Roadside Design Guide. Under the same scenario, the severity indexes at 7 ft (2.1 m) and 13 ft (4.0 m) were 4.3 and 4.6, respectively. The change between 1 and 7 ft (0.3 and 2.1 m) was 39 percent while the change between 7 and 13 ft (2.1 and 4.0 m) was only 7 percent. Therefore, these three values represented a vastly changing section of the severity-height plot from 1 ft (0.3 m) to 7 ft (2.1 m) and a vastly unchanging section from 7 ft (2.1 m) to 13 ft (4.0 m). As with the functional class and area type, RSAP combines the alternative and height into one parameter. As expected, the resulting accident costs were significantly different from the baseline accident costs. The parameters examined in the parametric study are outlined in Table 11.

Table 11. Baseline and Parameter Values

Parameter	Baseline	Variations	
Number of Lanes	4	2	6
ADT	50,000	10,000	90,000
Degree of Curvature	0	8 L	8 R
Grade	0	- 6%	+ 6%
Lane Width	12 ft	10 ft	14 ft
Traffic Growth Rate	2.0%	1.5%	2.5%
Percent Trucks	16%	5%	40%
Length of Feature	800 ft	100 ft	1500 ft
Offset	8 ft	4 ft	12 ft
Shoulder Width	4 ft	2 ft	6 ft
Height	7 ft	1 ft	13 ft

5.2 Baseline Accident Cost Determination

The speed limit was set to 55 mph (88.5 km/h) for all conditions. This was the maximum speed that RSAP can use because the speed distributions were based on a study done when the national speed limit was still set at 55 mph (88.5 km/h) [6, 33]. In addition, the average impact speed on interstate highways was approximately 45 mph (72.4 km/h), according to a study completed in 2009 [34]. The higher speed was chosen to represent a larger percentage of possible impacts than the average impact speed. Since 55 mph (88.5 km/h) was the highest allowable speed, it was used. The encroachment rate adjustment factor was set to 1 for all analyses because it is only used in specific situations when the Cooper encroachment data can be substituted with more accurate data. The segment length was set at 2,640 ft (804.7 m) simply to allow for enough space such that the number of encroachments could be accurately modeled. If the length is too small, Monte Carlo simulation may predict zero accidents on that segment, even if the encroachment frequency is not zero. The distance from the beginning of the first segment to the feature was set to 0 arbitrarily. This value was not significant because RSAP automatically places a segment in front of the specified segment in order to predict impacts away from the roadway, even at the beginning of the segment. The width was determined by the height and the slope. For example, on a 3:1 slope and a height of 7 ft (2.1 m), the width would be $3 \times 7 = 21$ ft (6.4 m). After inputting the remaining variables given in Table 11 into RSAP and running the program with a high level of convergence, a baseline accident cost report was produced. By rerunning the analysis 200 times with identical input values, as suggested in the RSAP Engineer's Manual, an average cost was determined to be $21,199.67 for all cases, except the highway division study, as shown in Table 12.

5.3 Parametric Analysis

Only one parameter from Table 11 was changed at a time, which demonstrated each parameter's impact on the accident cost. Each parameter was analyzed once using RSAP to determine its accident cost. In order to refine the parameter pool, engineering judgment was used to determine which variables were sensitive to change. The sensitivity analysis was conducted to reduce the number of the variables outlined in Table 11 such that the total number of required scenarios to simulate could be reduced.

To calculate the effect of changing a parameter, the baseline accident cost was calculated first, as noted in Section 5.2. Then, the accident costs were determined individually for each parameter as it was changed. Finally, the percent difference was calculated for each parameter, effectively measuring the influence of that parameter on the accident cost. Most parameters had two variations to the baseline. As a result, there were two new accident costs and two new percent differences for those parameters. In order to gage the parameter as a whole, the percent differences were averaged together for each parameter, where applicable. These average percent differences are shown in Table 12

Using engineering judgment, the bottom five parameters shown in Table 12 were excluded. This cutoff point included offset in the analysis but excluded the number of lanes. This was partially due to the fact that as the number of lanes was allowed to increase, the percent difference in accident cost was almost negligible. Also, some functional classes simply don't use four or more lanes, such as a rural local highway. The percent differences for the remaining parameters indicate a percent difference in accident cost of no more than 7 percent, making them insensitive to change.

Table 12. Accident Costs and Percent Differences for Each Parameter

Parameter	Baseline Accident Cost	Variation Accident Cost		Average Percent Difference
Degree of Curvature	$21,199.67	$ 50,245.39	$ 32,193.86	94%
Length of Feature	$21,199.67	$ 3,820.44	$ 39,353.44	84%
ADT	$21,199.67	$ 7,937.52	$ 31,568.47	56%
Grade	$21,199.67	$ 31,779.03	$ 32,129.55	51%
Height	$21,199.67	$ 7,390.78	$ 26,186.20	44%
Offset	$21,199.67	$ 27,441.54	$ 16,063.66	27%
Number of Lanes	$21,199.67	$ 17,206.76	$ 22,883.78	13%
Lane Width	$21,199.67	$ 22,965.74	$ 19,836.64	7%
Traffic Growth Rate	$21,199.67	$ 20,079.64	$ 22,387.09	5%
Shoulder Width	$21,199.67	$ 20,506.61	$ 20,547.96	3%
Percent Trucks	$21,199.67	$ 21,088.98	$ 21,385.30	1%

5.4 Detailed Study Recommendation

The alternative and the highway division were determined by the functional class independent of the results of the parameter study. The results indicate that those two parameters were in fact sensitive to change; however, they were not subject to the same changes for every functional class. The same alternatives were considered for most highways. The use of these alternative slopes is explained in more detail in Chapter 7. The division of the highway was dependent on the functional class. Freeways were divided only, and local highways were undivided only. Arterials included both divided and undivided classifications. Therefore, the parameters left to be altered and used to create an RSAP test matrix were the length of the feature, height, traffic volume, degree of curvature, percent grade, and offset. These parameters are highlighted in Table 12.

6 RSAP ALTERNATIVES

Three safety treatments were considered for this study. They were: (i) do-nothing; (ii) slope flattening; and (iii) guardrail installation. Each one of these treatments were modeled using RSAP and are described in the following sections.

6.1 “Do Nothing” Condition

Alternatives are compared to a baseline condition known as the “do-nothing” condition. The do-nothing option consists of applying no safety treatment to the roadside slope. This was done if the direct costs of flattening the slope were too expensive or if the severity of striking a guardrail outweighed the severity of striking the existing slope. For all rural local highways, a minimum slope of 2:1 was used, but for all other highway types, a minimum slope of 3:1 was adopted based on recommendations from *Guidelines for Guardrail Implementation* [30].

6.2 Slope Flattening

Soil must be transported to the site and compacted in place. The slope of the roadside is defined by a rise-over-run designation, with the rise always equal to 1 unit. For example, a slope with a rise of 1 unit and a run of 2 units would be designated as 2:1. The transportation of the soil would depend on the distance between the source of the soil and its destination. In some cases, there may be an excavation project nearby, and the cost of fill material would be almost nothing. In contrast, if soil must be transported over a great distance, the cost would have a large negative effect on this alternative’s viability. The contractor must compact the soil to meet the specifications set forth by the engineer. This means that the volume of fill to be transported must be larger than the volume of fill required. This volume difference must be accounted for when determining the cost of the material.

In addition to the cost of the fill, the cost to purchase the land immediately adjacent to the roadway must be ascertained. Once again, this cost may fluctuate significantly. Perhaps the state already owns the land, and the cost of the right-of-way (ROW) would be zero; or maybe the adjacent area is farmland, which could be a significant purchase. Because of the high uncertainty of the costs of this alternative, B/C ratios could not be estimated. Instead, only the numerator of the B/C ratio could be determined. What is certain is that as the slope gets flatter, its safety performance increases.

As a vehicle goes over an embankment, its center of gravity acts through a point outside of the geometric center of the vehicle. Steeper slopes cause the center of gravity to move farther out relative to the vehicle than on flatter slopes. Therefore, as the slope gets steeper, the likelihood of a rollover increases. Flatter slopes reduce the severity of each accident because the frequency of a rollover is reduced. As a result, the cost per accident decreases. For this study, only the values that have been pre-programmed into RSAP were used. Those slopes were 2:1, 3:1, 4:1, and 6:1.

6.3 Guardrails and Terminals

If slope flattening is not a feasible or economical option, the next alternative design to consider is to shield the existing slope with a guardrail system. This is considered a secondary option because impacts with the guardrail may be more dangerous than simply leaving the slope unprotected. As a vehicle strikes the guardrail, there is a propensity for vehicular instability, which could cause the vehicle to rollover. The vehicle may also vault over the guardrail and traverse the steep slope anyway. It could also be redirected into traffic or snag on rigid posts. Occupant risk may increase in the form of ride down accelerations or occupant impact velocities. Also, these systems are located closer to the roadway than the edge of the slope. Previous research demonstrates that guardrails can be adequately implemented on slopes as steep as 2:1, but this requires longer posts or closer post spacing and the use of the Midwest Guardrail System (MGS) [42]. Despite the ability to place the guardrail system immediately adjacent to the slope, the face of the guardrail is still closer to the roadway. Being closer, the impact probability would increase, as would the accident costs.

The RDG method for determining the length-of-need was chosen for this report for two reasons. First, it results in conservatively long lengths of guardrail. Second, it is most likely the more common of the two methods. All guardrails and terminals were designed at Test-Level 3 (TL-3) in order to safely redirect vehicles at speeds greater than 45 mph (72.42 km/h). The amount of guardrail required to shield the foreslope was determined based on the length of the slope adjacent to the roadway and the offset of this slope from the edge of the roadway. A more detailed description of how the length-of-need was calculated is presented in Section 8.2.

End terminals are required on the ends of most guardrail applications, especially on the end facing the primary direction of travel. In situations where a guardrail is used on the roadside of a divided highway, a terminal may not be required on the downstream end (facing opposing traffic), but in this study, it was included as part of the conservative design. These terminals were entered as TL-3 and were assumed to be 37.5 ft (11.4 m) long by 1.5 ft (0.5 m) wide, based on suggestions in the RDG [2].

6.4 Decision Tree

Usually, striking any obstacle is more hazardous than missing it. Therefore, if flattening a slope is warranted, it should be used. However, if flattening a slope is too expensive to implement, then the use of a longitudinal barrier should be examined. This decision tree is illustrated in Figure 9.

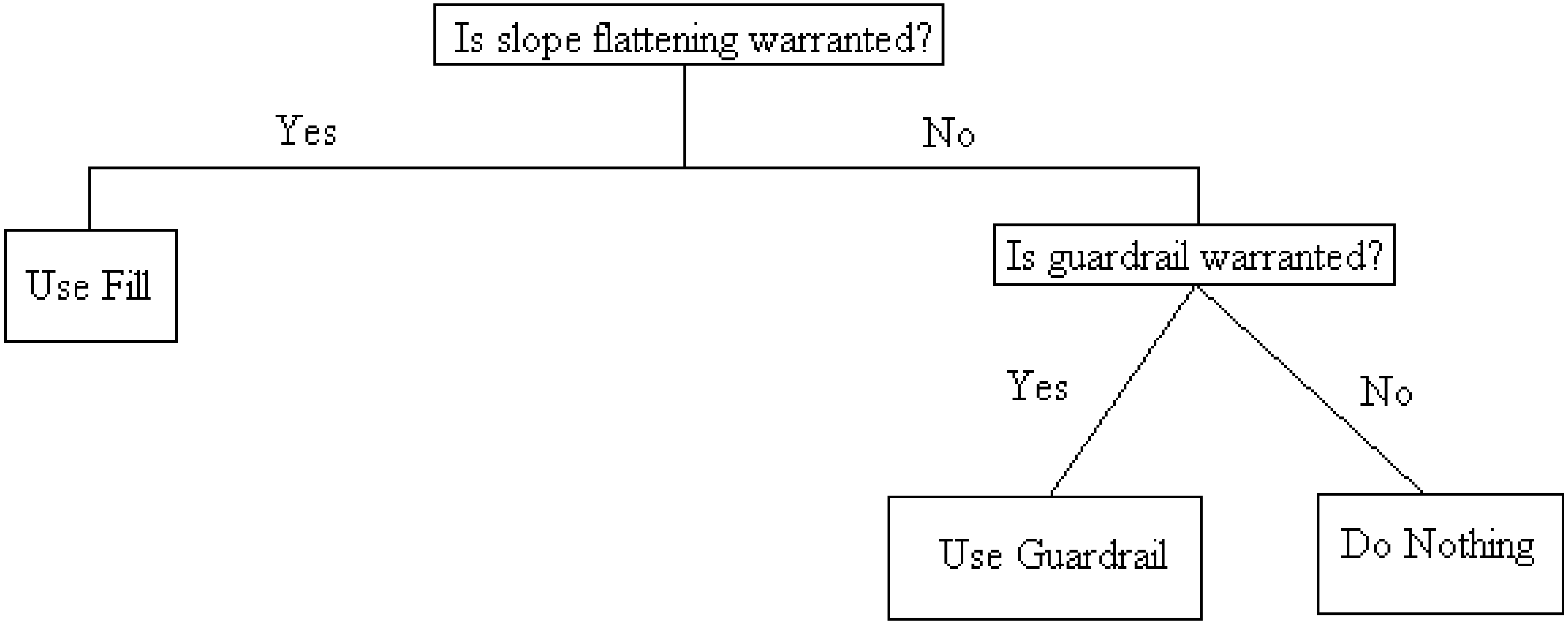


Figure 9. Alternative Decision Tree

7 RSAP INPUT VALUES

Parameters characterized by a low sensitivity were assigned a constant value throughout all analyses. The area type was grouped with the functional class (e.g. Rural Freeway) and was treated with the moderately sensitive parameters. Four lanes were used on freeways and divided arterials, but two lanes were used on undivided arterials and local roads. A shoulder width of 8 ft (2.4 m) was also used on all highway types except the freeway. This width was chosen to give law enforcement enough room to pull over to the side of the road, to give maintenance workers enough space, and to provide enough room for motorists to avoid accidents [43]. The shoulder width on a freeway was increased to 12 ft (3.7 m) to account for the increased traffic volume [44]. The location of the slope or guardrail system under examination was assumed to be on the right side of the roadway. Default values of 25 years and 4 percent were used for the design life and discount rate, respectively. The traffic growth rate was estimated to be 2 percent between the years 2010 and 2020 in the State of Wisconsin, and the percent of trucks was set at a constant 16 percent [35].

Features and values to be used in a detailed study are summarized in Table 13. Offset values were chosen to represent a range of values capable of modeling actual offsets. Similarly, the height of the embankment and the length of the feature were chosen to represent a range of practical values. The grades, degrees of curvature, and slopes were chosen from the National Cooperative Highway Research Program's (NCHRP) Report No. 638, and they varied depending on the functional class of the highway [30]. This report gave minimum design standards and are shown in Table 3. This table was applicable to the side slopes, horizontal curvature, and the percent grade. For the side slopes, all functional classes except the rural local/collector gave a maximum steepness of 3:1. For the rural local/collector highwar, the maximum steepness was 2:1. From these ranges, the sideslopes discussed in Section 6.2 were chosen.

From this information, representative values were chosen that would adequately describe the parameter while reducing the number of required RSAP runs. Three values were chosen for horizontal curvature and percent grade. Those three values were modified per functional class to describe the range shown in Table 3. When possible, the increments between each value were kept equal. For example, the degrees of curvature for a rural local highway were 0, 4, and 8 degrees to the left (L), with the latter representing the absolute maximum value given in NCHRP Report No. 638. Left curves and downgrades were selected over their counterparts because they represented the worst case for those parameters. By using only the worst case, the results were conservative, and the number of RSAP runs was reduced. The horizontal curvatures and percent grades are summarized in Table 13.

The final three parameters described in Table 13 were constant for each functional class and alternative. Again, three values were used to provide enough data to interpolate at any value while limiting the number of RSAP simulations that were required. Each of the parameters had equal increments between their values. In general, and when extreme values are avoided, the values of these parameters are arbitrary because the results will be used in linear interpolation to determine accident costs at any length, height, or offset. As the length of the feature increased, the accident frequency would increase linearly as well. As a result, the actual values used in RSAP were only significant in the interpolation of the results of the study. The height selection was discussed in the parametric study, and the same values were used in the detailed study. Recall that the 7-ft (2.1-m) height was close to an inflection point in the SI-height plot. The lower height was representative of a high-slope portion of that plot, while the upper height was representative of the low-slope portion of that plot. For the final parameter, offset, values were chosen at relatively close proximity to the roadway. As the offset increases, the accident frequency decreases. In order to capture the effect of a more turbulent region of encroachments, offsets of diminished magnitude were selected.

Table 13. RSAP Input Values

	Rural Local	Urban Local	Rural Arterial	Urban Arterial	Freeway
Alternatives	1:2 Slope 1:3 Slope 1:4 Slope 1:6 Slope Guardrail	1:3 Slope 1:4 Slope Guardrail	1:3 Slope 1:4 Slope 1:6 Slope Guardrail	1:3 Slope 1:4 Slope 1:6 Slope Guardrail	1:3 Slope 1:4 Slope 1:6 Slope Guardrail
Degree of Curvature (°)	0, 4, 8L	0, 3, 6L	0, 3, 6L	0, 4, 8L	0, 2, 3L
Grade (%)	0, -4, -8	0, -6, -12	0, -3, -6	0, -3, -6	0, -2, -3
Length of Feature, ft (m)	200 (60.96) 800 (243.84) 1400 (426.72)	200 (60.96) 800 (243.84) 1400 (426.72)	200 (60.96) 800 (243.84) 1400 (426.72)	200 (60.96) 800 (243.84) 1400 (426.72)	200 (60.96) 800 (243.84) 1400 (426.72)
Height, ft (m)	1 (0.30) 7 (2.13) 13 (3.96)	1 (0.30) 7 (2.13) 13 (3.96)	1 (0.30) 7 (2.13) 13 (3.96)	1 (0.30) 7 (2.13) 13 (3.96)	1 (0.30) 7 (2.13) 13 (3.96)
Offset, ft (m)	2 (0.61) 7 (2.13) 12 (3.66)	2 (0.61) 7 (2.13) 12 (3.66)	2 (0.61) 7 (2.13) 12 (3.66)	2 (0.61) 7 (2.13) 12 (3.66)	2 (0.61) 7 (2.13) 12 (3.66)

8 DIRECT COSTS

8.1 Required Fill Material for Slope Flattening

Contractors bid on fill obligations by unit of volume, usually cubic yards. The volume of fill required to flatten a slope can be determined for each alternative. The total required volume can be estimated using a cross-section similar to the one shown in Figure 10, assuming the existing slope is a 2:1.

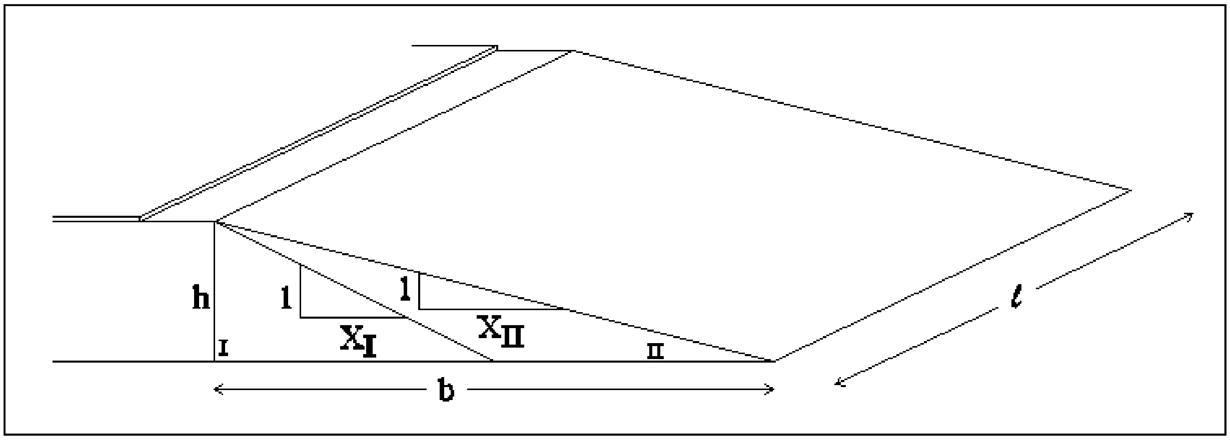


Figure 10. Cross-Sectional Area Required to Flatten Slope on Rural Local Highway

First, the cross-sectional area of the new slope can be determined assuming a right triangle was made and the face of the slope acted as the hypotenuse, as shown in Figure 10. The area of the triangle labeled with a Roman numeral I can be determined assuming a constant slope of 2:1 for rural local highways and 3:1 for all other highway types. This area, A_I, was subtracted from the total area, A, thus determining the required cross sectional area, A_{II}, which can be used to determine the volume needed to flatten a slope. The volume was derived by Equations 5 through 16.

$$A = \frac{1}{2} b_2 h \tag{5}$$

$$b_2 = hX_{II} \tag{6}$$

By substituting Equation 6 into Equation 5, the total cross-sectional area of the flattened slope could be determined. This result is shown as Equation 7

$$A = \frac{1}{2} X_{II} h^2 \tag{7}$$

Next, the cross-sectional area of the original slope was calculated. In terms of height and width, this area was given by Equation 8.

$$A_I = \frac{1}{2} b_1 h \tag{8}$$

$$b_1 = h X_I \tag{9}$$

By substituting Equation 9 into Equation 8, the cross-sectional area of the original slope could be determined in terms of the height of the slope. This cross-sectional area of the original slope is shown in Equation 10.

$$A_I = \frac{1}{2} X_I h^2 \tag{10}$$

Next, the cross-sectional area of the fill material needed to create the desired slope was determined in terms of the height and the flattened slope (1V:XH). This general equation is shown in Equation 11.

$$A_{II} = A - A_I \tag{11}$$

By substituting Equations 7 and 10 into Equation 11, the final required cross-sectional area in terms of the height and the difference of the two slopes is shown in Equation 12.

$$A_{II} = \frac{1}{2} h^2 (X_{II} - X_I) \tag{12}$$

The volume required to flatten the original slope to the desired slope is calculated by multiplying the length of the slope parallel to the roadway by the area calculated from Equation 12. This fill volume calculation is shown in Equation 13 in terms of the cross-sectional area and in Equation 14 in terms of the height and slope differences of the two slopes.

$$V_{fill} = A_{II} \times l \tag{13}$$

$$V_{fill} = \frac{1}{2} h^2 l (X_{II} - X_I) \tag{14}$$

The volume may need to be adjusted for bulking or shrinking. The shrinkage factor ($\Delta V/V_f$) of soil is a function of the unit weight of the fill material and the cut material.

$$\frac{\Delta V}{V_f} = \left[\frac{(\bar{\gamma}_d)_f}{(\bar{\gamma}_d)_c} - 1\right] \tag{15}$$

Where $(\bar{\gamma}_d)_f$ is the average dry unit weight of fill, and $(\bar{\gamma}_d)_c$ is the average dry unit weight of borrow. The volume of borrow required to satisfy the V_{fill} demand is always at least as much as the V_{fill} and is often more. The equation to calculate the total volume required from a borrow site is shown in Equation 16

$$V_{borrow} = V_{fill}\left(1 + \frac{\Delta V}{V_f}\right) \tag{16}$$

In addition to the cost of materials, the cost of the right of way may need to be included. In some areas, this may be extremely expensive and force the engineer to abandon the idea of a flatter slope.

8.2 Required Material for a Guardrail System

Figure 11 illustrates the variables required to determine the guardrail length-of-need. The tangent length of the barrier immediately upstream of the slope (L_1) was assumed to be 25 ft (7.6 m). This assumption was based on sample designs found in the RDG [2]. The shy line was defined as the point from the edge of the travel way at which the motorist would not be inclined to reduce the speed or direction of the vehicle. For 55 mph (88.5 km/h), the shyline is located 7.2 ft (2.2 m) from the edge of the travel way [2]. Flared guardrail was used to limit the reaction of a motorist to the guardrail by starting it further away from the road than the straight segment of guardrail. In addition, the use of flared guardrail sections reduces the total length-of-need for the guardrail installation. For scenarios with a guardrail offset of 2 and 7 ft (0.6 and 2.1 m) along the straight segment (inside the shy line), a flare rate of 24:1 was used. Outside the shy line, a flare rate of 16:1 was used. These flare rate recommendations were given in the Roadside Design Guide [2]. This is represented in Figure 11 as the section of guardrail not parallel to the roadway. To determine the total length of guardrail to be used in RSAP when the length of the terminal is 37.5 ft (11.4 m) and to determine the annual cost of installation, the following equations were used:

$$L = 2 \cdot (x - L_1 - 37.5) + l \tag{17}$$

$$x = \frac{(H \cdot S) + (L_1 \cdot F)}{F + \left(\frac{H \cdot S + L_2}{L_R}\right)} \tag{18}$$

Where

$\mathrm{H} = $ Height (ft) of the foreslope

$\mathrm{S} = $ Slope

$\mathrm{F} = $ Flare rate $= \mathrm{b/a}$

$\mathrm{L_1} = 25$ ft

$\mathrm{L_2} = $ Offset (ft)

$\mathrm{L_R} = $ Runout length

$\mathrm{L} = $ Total length of guardrail required (ft)

$l = $ Length of the foreslope (ft)

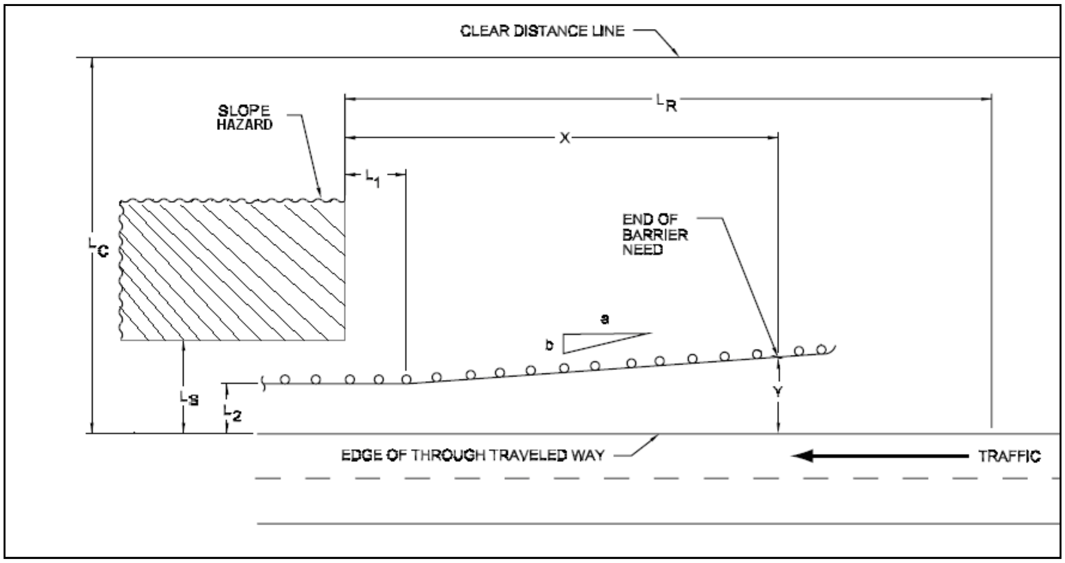


Figure 11. Guardrail Layout Variables

The runout length, L_R, is the distance for a vehicle to come to a stop once it has left the roadway. From the RDG, it was determined to be 280 ft (85.3 m) for traffic volumes less than 800 vehicles per day (vpd), 315 ft (96.0 m) for traffic volumes between 800 and 2,000 vpd, 345 ft (105.2 m) for traffic volumes between 2,000 and 6,000 vpd, and 360 ft (109.7 m) for traffic volumes greater than 6,000 vpd [2]. The run-out length was correlated to the traffic volume because the Hutchinson and Kennedy encroachment data was used to simulate encroachment events, and, in that study, the encroachment frequency was dependent on the traffic volume [12]. Based on the height and slope of the foreslope, the width of the base of the slope was calculated. Given these parameters, basic geometry derived from the plan view was used to determine the lateral offset from the edge of the travel way of each point of interest along the system. This included the beginning of the terminal, the beginning of the guardrail, the end of the first flared section of guardrail, the end of the straight segment of guardrail, and the beginning of the second terminal. These lateral offsets were entered into RSAP.

Terminals were placed at both ends of the guardrail. For a TL-3 condition, many terminals are 37.5 ft (11.4 m) long and 1.5 ft (0.5 m) wide, as suggested by the Roadside Design Guide [2].

8.3 Direct Costs

The cost to install a new system or upgrade an existing one needs to be annualized for each alternative. The total cost per year takes into account the design life of the system as well as an interest rate. Equation 19 was used to determine the direct cost of each alternative, which can be used to determine the denominator of the B/C ratio.

$$DC = P \cdot \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \tag{19}$$

Where

DC = Annualized direct cost to install the system

P = Total cost of material, labor, and right-of-way

i = Interest rate as a decimal

n = Design life (years)

9 ACCIDENT COSTS

9.1 Societal Costs

Once the severity of an accident is determined, the cost of that accident can be calculated. The RSAP simulation determines the probability of an accident resulting in a certain injury level such as death or severe injury. For each level of injury, there is an associated cost.

Accident cost figures can be found from multiple sources including the RDG and the FHWA. The FHWA gives a data set that includes a person's willingness to pay to avoid injury or fatality. Therefore, it is strongly recommended that the FHWA's comprehensive accident cost values be used. However, their values are based on the value of the US dollar in 1994. Those costs were then increased using the estimated Gross Domestic implicit price deflator for the year 2014. Therefore, those values were adjusted for the year 2014 using Equation 20. These values are given in Table 14.

$$AccCost = P\left[\frac{GDP_{2014}}{GDP_{1994}}\right] \tag{20}$$

Where the *AccCost* is the accident cost in 2014, *P* is the accident cost given by the FHWA in 1994, GDP_i is the implicit price deflator for 1994 or 2014.

Table 14. FHWA Comprehensive Accident Costs

Accident Type	Accident Costs ($) for 1994	Accident Costs ($) for 2009
Fatal	$ 2,600,000	$ 3,850,942
Severe Injury	$ 180,000	$ 266,604
Moderate Injury	$ 36,000	$ 53,321
Minor Injury	$ 19,000	$ 28,142
Property Damage Only	$ 2,000	$ 2,962

The accident types and associated costs given in Table 14 needed to be converted to an SI range from 0 to 10, with 10 being an absolutely fatal event. This was done by using the injury level percents shown in Table 2 and the costs given in Table 14. A weighted average method was used. For demonstration, the cost of a severity index 5 is calculated below. The results of this method for all SI's are given in Table 15. For severities between whole numbers, the accident cost can be linearly interpolated from the table.

$$AccCost_{SI=5} = (0.0 \times 2{,}962) + (0.15 \times 2{,}962) + (0.22 \times 28{,}142) + (0.45 \times 53{,}321) + (0.10 \times 266{,}604) + (0.08 \times 3{,}850{,}942) = \$365{,}366$$

Table 15. Cost of each SI

Severity Index (SI)	Accident Cost
0	$ -
0.5	$ 2,962
1	$ 5,958
2	$ 12,027
3	$ 63,215
4	$ 155,252
5	$ 365,366
6	$ 771,996
7	$ 1,253,067
8	$ 2,008,711
9	$ 2,939,928
10	$ 3,850,942

So far, only the unadjusted accident cost has been determined for any SI. The actual accident cost was determined using adjustment factors for the encroachment speed and angle, vehicle orientation, vehicle type, and lane departure/encroachment direction. The adjusted accident cost was then multiplied by the probability of the vehicle encroaching through a given lateral offset. Finally, this analysis was repeated until the resulting average encroachment accident cost converged to within one percent.

9.2 Accident Cost Equations Determined by RSAP

For each considered scenario, there were several traffic volumes simulated to understand the effect of traffic volume on the accident cost. The relationship was approximately linear. For each functional class, a linear regression was conducted in which the regression line was forced through the origin (zero traffic equals zero accident cost). As a result, a simple y = bx equation could be generated for all scenarios, were y is the accident cost, b is the slope of the regression line, and x is the traffic volume (ADT). The slope, b, is given with each scenario in the Appendixes, and the equation used to determine b is given below as Equation 21. Using this slope, the accident cost can be calculated as a function of the ADT by using Equation 22. An example of how to use these tables is given in the following section.

$$b = \frac{\sum x_i y_i}{\sum x_i^2} \tag{21}$$

$$AccCost = b \times ADT \tag{22}$$

Where x_i is the ADT used in the study, and y_i is the associated accident cost. For a demonstration of this equation's validity, a plot of the accident cost verses ADT for a 2:1 foreslope, rural local, straight, three percent grade, 1400-ft (426.7-m) long, 7-ft (2.1-m) high highway with an offset of 7 ft (2.1 m) was created from the accident cost data given in Table 16. The slope was calculated by dividing 11,220,313 (xy) by 1,330,625 (x^2) resulting in a quotient of 8.432, as is given in Appendix B. The plot of the accident costs verses ADT and the regression line are shown in Figure 12.

Table 16. Accident Costs for a 2:1 Rural Local Highway

i	x (ADT)	y (AccCost)	xy	x^2
1	50	455.2	22760	2500
2	75	672.03	50402.25	5625
3	100	903.81	90381	10000
4	250	2214.46	553615	62500
5	500	4292.41	2146205	250000
6	1000	8356.95	8356950	1000000
Sum:			11,220,313	1,330,625

$$b = \frac{11{,}220{,}313}{1{,}330{,}625} = 8.432$$

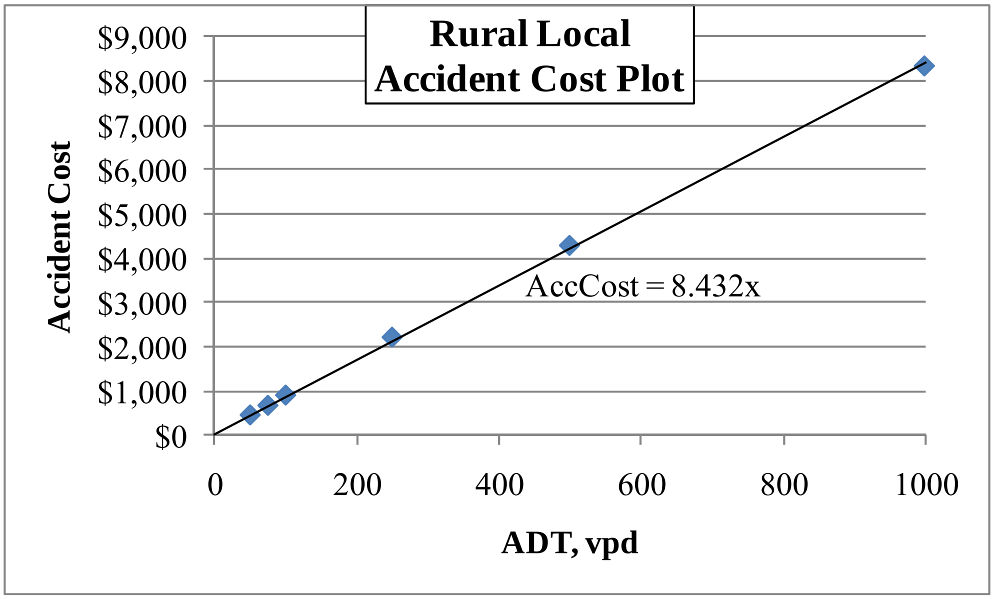


Figure 12. Accident Cost vs. ADT for a 2:1 Rural Local Highway

9.3 Using the *Benefit-Cost Analysis of Foreslopes Program*

9.3.1 Background

Looking up values in the appendices of this report can be cumbersome and may lead to errors. In addition, the interpolation between accident costs, when needed, can exponentially complicate the determination of the accident cost. If none of the parameters (degree of curvature, grade, length, height, and offset) match the values used in the study, 32 different accident costs would be required in order to completely interpolate between all of the known values and calculate one overall accident cost. Clearly, the need exists for a computer program that is capable of looking up the coefficient presented in this report and using it to calculate an accident cost, using interpolation where needed. In response to this need, Microsoft Excel was used to create the *Benefit-Cost Analysis of Foreslopes Program (BCAFP)*, which contains a series of spreadsheets that allow the user to input the known values of the previously described parameters as well as a traffic volume and material cost. Other sheets were included that contained the calculations required for each functional class. One sheet contained the results for every scenario involving each functional class and design alternative, which are presented in this report in Appendix B through Appendix CC.

9.3.2 Development of BCAFP

The first spreadsheet in the Microsoft Excel file is reserved for user input and contains the design recommendation based on accident and direct costs. This sheet contains dropdown menus to select the functional class and the design alternatives. Then, the user is allowed to specify the degree of curvature, percent grade, as well as the length, height, and offset of the roadside feature. In addition, the user must input a traffic volume, ADT, in vehicles per day (vpd), as well as the design speed, minimum B/C ratio, the maximum required right-of-way, and the costs for the different materials used in the design alternatives. This sheet also warns the user of input errors, like when a 2:1 slope is used anywhere but on a rural local highway. It also warns the user when extrapolation is used to estimate accident cost, prompting the user to use engineering judgment as to whether or not to use the accident cost. In regards to the maximum required right-of-way, the engineer may enter a value to override calculations based on the RDG. These calculated values account for the design speed, traffic volume, and slope steepness. For 3:1 slopes, it was assumed that beyond the 3:1 slope was a recoverable slope between 5:1 and 4:1, such that the required clear zone was the width of the new slope material plus the required clear zone of a recoverable slope. If the user input was less than the calculated value, the user input alone was used for all slope alternatives.

The second sheet calculates the direct costs of each design alternative by estimating the volume of required fill material or the length of required guardrail. This was done by using Equations 14, 17, and 18. Then, the quantity of the material was multiplied by the specified unit cost, and each material cost was summed to determine a principal cost, from which the direct cost was calculated using Equation 19. The third sheet displays the accident costs for each design alternative as determined in the final seven sheets. The fourth sheet assembles a B/C ratio matrix by using Equation 36. This sheet also interprets the matrix and determines the best overall design alternative, according to the B/C ratios.

The fifth sheet contains a combination of the results shown in Appendix B through Appendix CC. Each scenario was assigned an index number, which was later used to lookup values based on the input parameters. In total, there were 6,804 index values covering freeways, divided rural arterials, undivided rural arterials, rural locals, divided urban arterials, undivided urban arterials, and urban locals. Each of those functional classes could contain up to four slopes (2:1, 3:1, 4:1, and 6:1) and one guardrail system.

The final seven sheets were created for calculation purposes, each one containing calculations pertinent to one of the seven functional classes mentioned in the preceding paragraph. Each sheet imports data entered in the “BC Analysis” tab. Using these input parameters, the program determines the two standard values surrounding the user’s input value. Those standard values were those chosen for the RSAP simulation. These two values were designated as low (L) and high (H), relative to the input value. For example, if the user specifies a height of 4 ft (12 m), the low value programmed into RSAP was 1 ft (0.3 m), and the high value was 7 ft (2.1 m). Once low and high values were determined for each input parameter, the pertinent coefficients for those low and high values were looked up from the “Coefficients” tab. Once the coefficients were determined, the program interpolated between the two values to determine the proper coefficient for the user’s input value. This interpolation process could become very complex. It was accomplished by first interpolating between offset values. The process continued next by interpolating between heights, lengths, grades, and finally degrees of curvature. The interpolation tree has been illustrated in Figure 13. This tree only shows half of the interpolation process. The top entry represents the low value of the degree of curvature. The other half of the tree would show the high value. The final coefficient was determined by interpolating between these two halves, using the input value for the degree of curvature.

Finally, when a parameter’s value falls outside the range of used values, interpolation cannot be used. Instead, extrapolation beyond the last known point must be used. This was accomplished by using the slope between the closest two known parameters and applying this slope to the difference between the values of the out-of-range and in-range parameters.

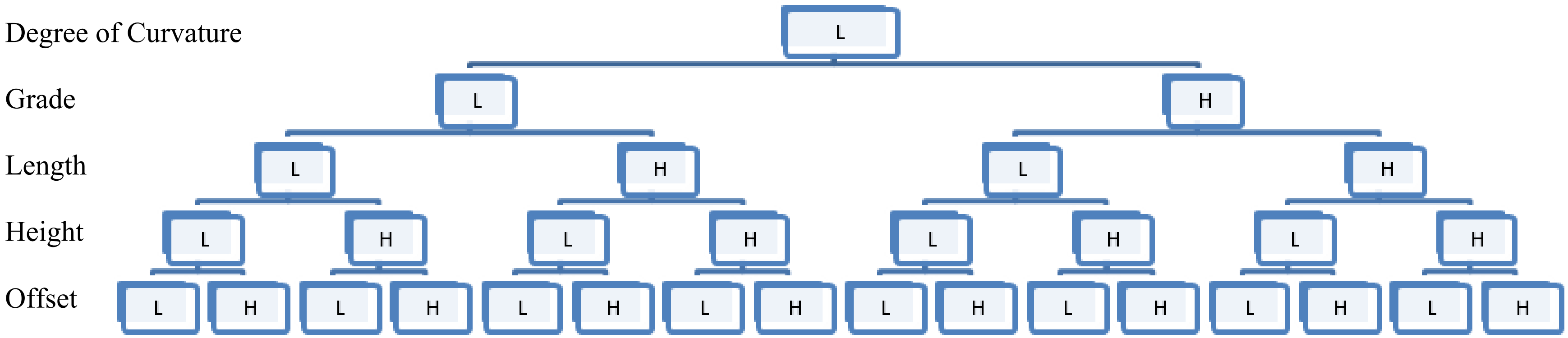


Figure 13. Interpolation Tree used in BCAFP

9.3.3 Using BCAFP

On the "BC Analysis" tab, the user may select the functional class from a drop down menu. Then, the user must select a design alternative. The options include foreslopes of 2:1, 3:1, 4:1, and 6:1 in addition to a Guardrail option. According to the design standards referenced in NCHRP Report No. 638, 2:1 foreslopes are only used on rural local highways. Additionally, 6:1 foreslopes are not used on urban local highways. If the user attempts to use these two slopes with functional classes that violate the design standards, BCAFP displays a warning message next to the input parameter that reads "Cannot Use a 1V:XH Foreslope."

The remaining parameters are not selected from dropdown menus. Instead, the user is allowed to specify any input value, within limits that will be discussed in the next section, to any degree of precision. If the input value exceeds the upper value used in the study or is less than the lowest value, the cell next to the parameter will display a warning message that says, "Extrapolation Used." The warning is intended to prompt the engineer to use judgment in determining if the accident cost is reasonable for the scenario. When the input value falls outside the range used in the study, interpolation cannot be done. As a result, extrapolation was used. The final input value is the traffic volume (ADT). This number will be used in the accident cost equations outlined in Section 9.2.

Once the input parameters are completed, BCAFP determines the coefficients that were determined by interpolation or extrapolation. The equations given in Section 9.2 were used to calculate the accident cost. Finally, using the material costs, the direct costs were determined for each design alternative, and a B/C ratio was determined for each alternative comparison, resulting in a B/C ratio matrix. BCAFP then interoperates this matrix to recommend to most cost-effective design.

9.3.4 Limitations of BCAFP

The coefficients used by BCAFP were determined as outlined in this report. That is, they were based on results from RSAP. RSAP itself has limitations ranging from the data it uses for encroachment frequency to programming errors. These limitations are highlighted in Chapter 12 and are detailed more explicitly in the draft interim report for NCHRP Project 22-27 [16].

The known values of the coefficients fall within a specified range of known input parameters. For example, the range of the length of the feature was 200 to 1,400 ft (61.0 to 426.7 m). As a result, if the accident cost was required for a scenario that falls outside this range, extrapolation was required. However, this was less certain than interpolation results between known values. The engineer is encouraged to use judgment to determine if the accident costs determined by extrapolation are representative of the scenario.

9.4 Accident Cost Trends for Each Parameter

Several parameters contributed to the accident cost. Each contributed in different magnitudes. Some increased the accident cost while others decreased it. The parameters that were allowed to vary and that can be selected by the engineer were as follows: (1) design alternative; (2) traffic volume; (3) degree of curvature; (4) grade; (5) length of the feature; (6) height of the feature; and (7) offset of the feature from the edge of the travel way. To understand and demonstrate the effect of each of these parameters on the accident cost, bar graphs were created to show how the accident cost fluctuates when only one of the seven parameters is changed. In general, four cases were used to study each parameter. For example, the traffic volume, ADT, for a freeway varied from 10,000 vpd (Case 1) to 100,000 vpd (Case 4). In this example, all other parameters used in Case 4 were the same as used in Case 1 (e.g. Case 4 degree of curvature was 0 degrees when examining ADT). The case descriptions for each functional class and each parameter are detailed in Table 17.

For all functional classes, slope flattening and increasing the offset reduced the accident cost. As the degree of curvature and the percent grade increased, the accident cost remained steady until the increase became significant, like in Case 4. For this case, the accident cost for these two parameters was always higher than for zero degrees of curvature and zero percent grade. The height tended to increase the accident cost, but it was not usually a significant increase. For a freeway, the cost of Case 4 (13 ft high) was more than twice as much as Case 1 (1 ft high), but for an undivided rural arterial, the cost of Case 4 was only 12 percent higher than Case 1. Uniformly, an increase in traffic volume and feature length resulted in a significant increase in accident cost, as is intuitive.

The most revealing trends of all the functional classes could be found in the alternatives. Naturally, the accident costs decreased as the slope was flattened. However, the largest decrease in cost was seen in changing from a 3:1 foreslope to a 4:1. For example, the accident cost was reduced by a factor of 10 on undivided rural arterial highways for a change from 3:1 to 4:1, but a change from 4:1 to 6:1 reduced the accident cost by a factor of only 2. In addition, it was shown that implementing guardrail (Case 4 of the alternatives) was extremely more costly than using slope flattening. As a result, the engineer is encouraged to exhaust all possible slope flattening alternatives before considering the use of a guardrail system. The trends corresponding to the cases outlined in Table 17 are demonstrated graphically in Figure 14 through Figure 20.

Table 17. Trend Analysis Parameters and Their Values

Freeway							
	Alternative	ADT (vpd)	Degree of Curvature	Grade (%)	Length, ft (m)	Height, ft (m)	Offset, ft (m)
Case 1	3:1	10000	0	0	200 (61.0)	1 (0.3)	2 (0.6)
Case 2	4:1	40000	1	1	600 (182.9)	5 (1.5)	5 (1.5)
Case 3	6:1	70000	2	2	1000 (304.8)	9 (2.7)	9 (2.7)
Case 4	Guardrail	100000	3	3	1400 (426.7)	13 (4.0)	12 (3.7)
Rural Arterial (Divided and Undivided)							
	Alternative	ADT (vpd)	Degree of Curvature	Grade (%)	Length (ft)	Height (ft)	Offset (ft)
Case 1	3:1	1000	0	0	200 (61.0)	1 (0.3)	2 (0.6)
Case 2	4:1	10000	2	2	600 (182.9)	5 (1.5)	5 (1.5)
Case 3	6:1	20000	4	4	1000 (304.8)	9 (2.7)	9 (2.7)
Case 4	Guardrail	30000	6	6	1400 (426.7)	13 (4.0)	12 (3.7)
Rural Local							
	Alternative	ADT (vpd)	Degree of Curvature	Grade (%)	Length (ft)	Height (ft)	Offset (ft)
Case 1	3:1	50	0	0	200 (61.0)	1 (0.3)	2 (0.6)
Case 2	4:1	300	3	3	600 (182.9)	5 (1.5)	5 (1.5)
Case 3	6:1	700	5	5	1000 (304.8)	9 (2.7)	9 (2.7)
Case 4	Guardrail	1000	8	8	1400 (426.7)	13 (4.0)	12 (3.7)
Urban Arterial (Divided and Undivided)							
	Alternative	ADT (vpd)	Degree of Curvature	Grade (%)	Length (ft)	Height (ft)	Offset (ft)
Case 1	3:1	1000	0	0	200 (61.0)	1 (0.3)	2 (0.6)
Case 2	4:1	10000	3	2	600 (182.9)	5 (1.5)	5 (1.5)
Case 3	6:1	20000	5	4	1000 (304.8)	9 (2.7)	9 (2.7)
Case 4	Guardrail	30000	8	6	1400 (426.7)	13 (4.0)	12 (3.7)
Urban Local							
	Alternative	ADT (vpd)	Degree of Curvature	Grade (%)	Length (ft)	Height (ft)	Offset (ft)
Case 1	3:1	50	0	0	200 (61.0)	1 (0.3)	2 (0.6)
Case 2	4:1	300	2	4	600 (182.9)	5 (1.5)	5 (1.5)
Case 3	6:1	700	4	8	1000 (304.8)	9 (2.7)	9 (2.7)
Case 4	Guardrail	1000	6	12	1400 (426.7)	13 (4.0)	12 (3.7)

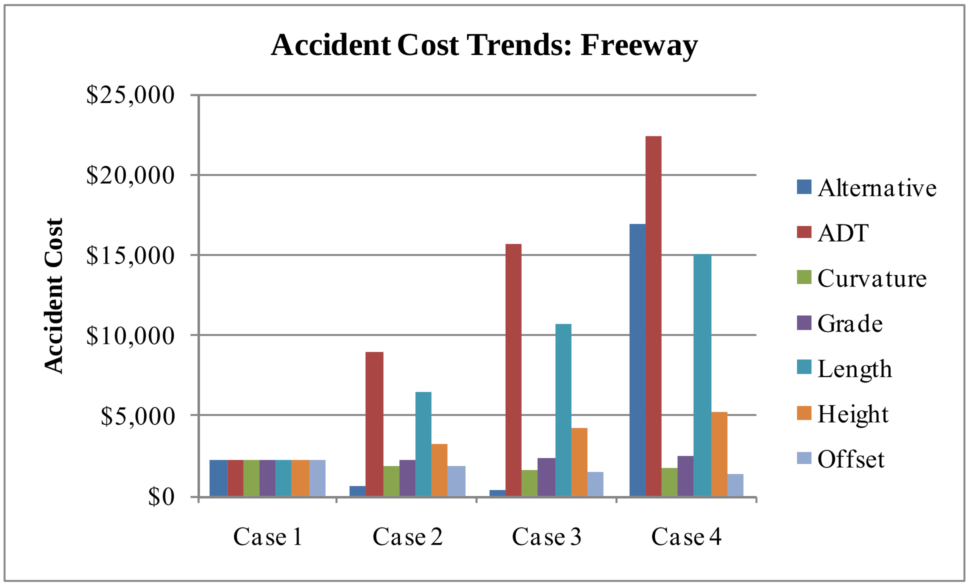


Figure 14. Accident Cost Trend of a Freeway

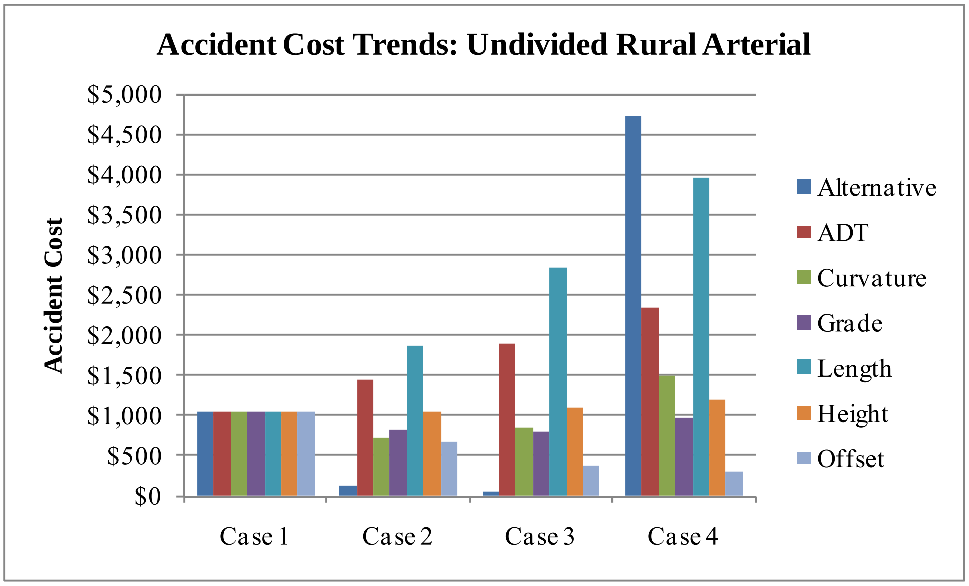


Figure 15. Accident Cost Trend of an Undivided Rural Arterial

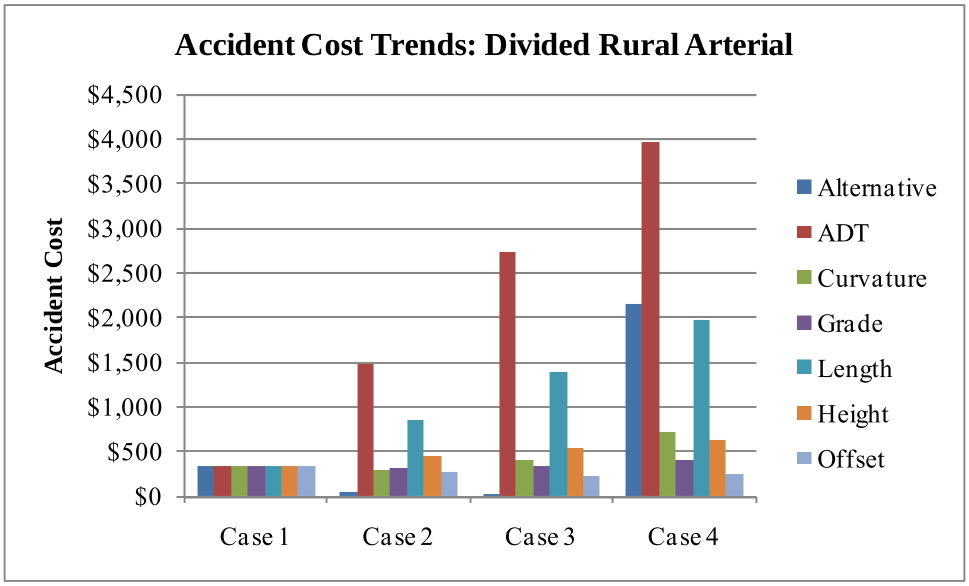


Figure 16. Accident Cost Trend of a Divided Rural Arterial

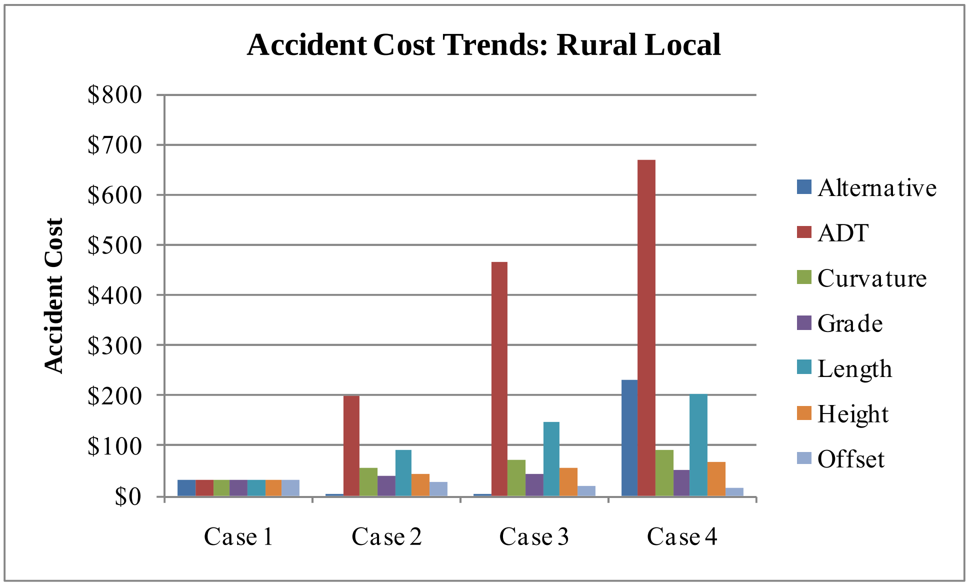


Figure 17. Accident Cost Trend of a Rural Local Highway

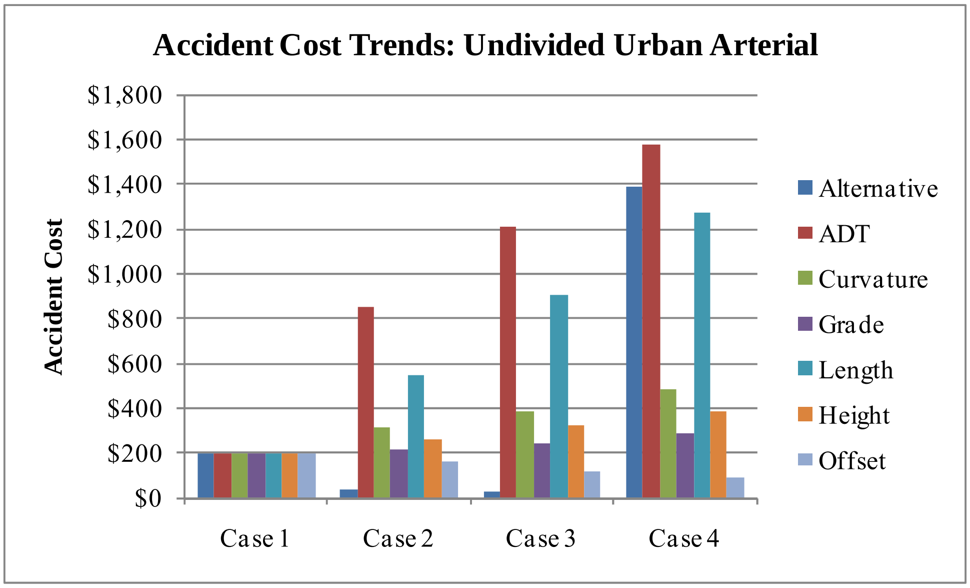


Figure 18. Accident Cost Trend of an Undivided Urban Arterial

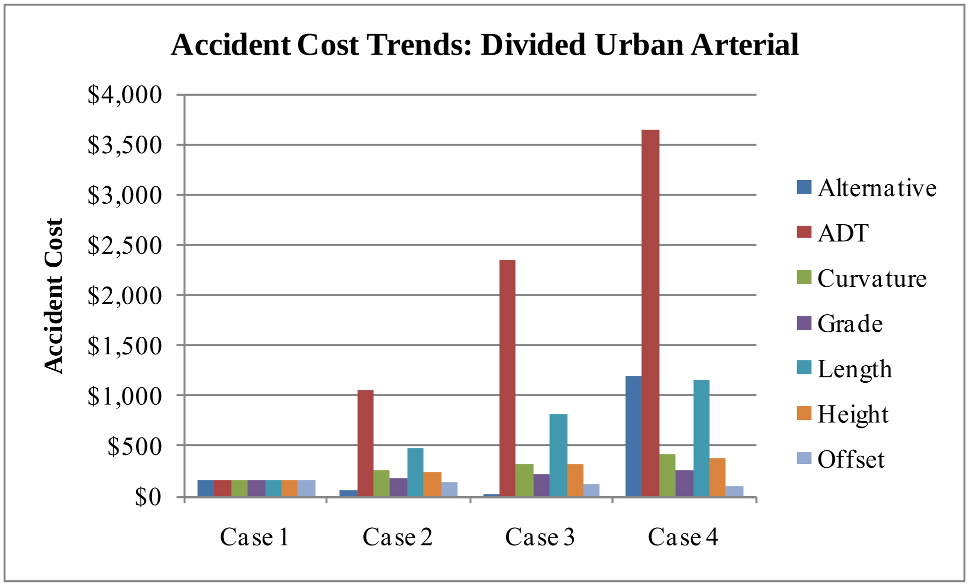


Figure 19. Accident Cost Trend of a Divided Urban Arterial

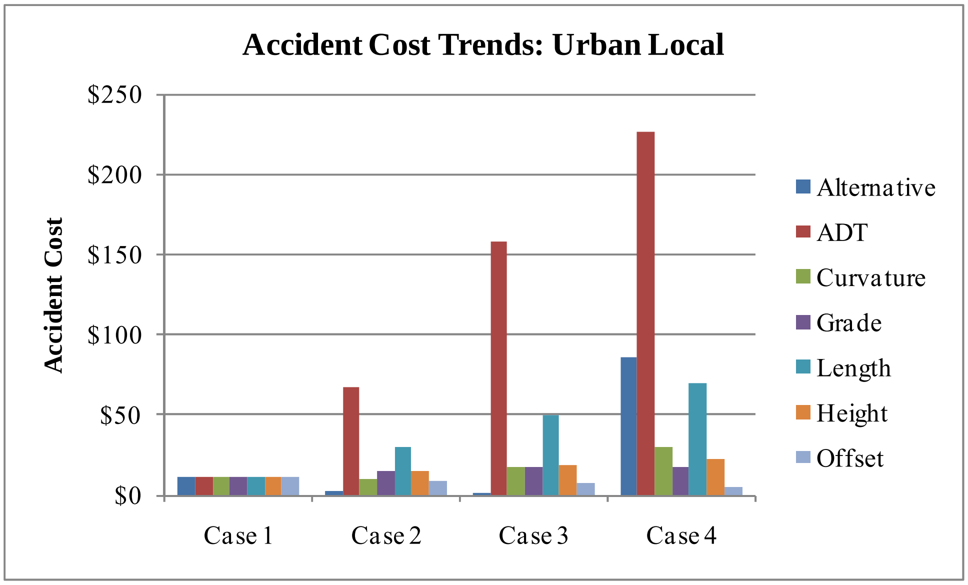


Figure 20. Accident Cost Trend of an Urban Local Highway

9.5 Determining an Accident Cost

9.5.1 Example 1 – Rural Local

Given:

- 2:1 slope
- ADT = 400 vpd
- Degree of Curvature = 0 degrees
- Grade = 4 percent
- Length of Feature = 200 ft (61.0 m)
- Height of Feature = 7 ft (2.1 m)
- Offset of Feature from the Edge of the Traveled Way = 7 ft (2.1 m)

From Appendix B (Accident Costs for a 2:1 Slope), b = 1.346. The accident cost, *AccCost*, is given by:

$$AccCost = b \times ADT = 400 \times 1.346 = \$538.40$$

From BCAFP, b = 1.346 and the accident cost was $538.44. The slight difference in the results was due to rounding errors. The Excel file carried out calculations without rounding until the final step, when the accident cost was calculated. To save space, the coefficients in the Appendixes were rounded to three decimal places.

9.5.2 Example 2 – Freeway

Given:

- 4:1 slope
- ADT = 63,000 vpd
- Degree of Curvature = 2 degrees
- Grade = 2 percent
- Length of Feature = 400 ft (121.9 m)
- Height of Feature = 6 ft (1.8 m)
- Offset of Feature from the Edge of the Traveled Way = 12 ft (3.7 m)

The height and the length of the feature cannot be directly read from the table. Therefore, linear interpolation between 1 and 7 ft (0.3 and 2.1 m) was required for the height, and between 200 and 800 ft (61.0 and 243.8 m) for the length. To do this, Appendix J was used. The b-coefficient of a 200-ft (61.0-m) long, 1-ft (0.3-m) high feature was 0.020 making the accident cost $1,260 per year. The b-coefficient of a 200-ft (61.0-m) long, 7-ft (2.1-m) high feature was 0.099 making the accident cost $6,237. The interpolation was done as follows:

$$AccCost = \left[\left(\frac{6ft - 1ft}{7ft - 1ft}\right) \times (\$6{,}237 - \$1{,}260)\right] + \$1{,}260 = \$5{,}407.50$$

Next, the process was repeated for an 800-ft (243.8-m) long feature at 1-ft (0.3-m) and 7-ft (2.1-m) high. The corresponding b-coefficients were 0.129 and 0.532, respectively. From these coefficients, the accident costs were \$8,127 and \$33,516. The interpolation was done as follows:

$$AccCost = \left[\left(\frac{6ft - 1ft}{7ft - 1ft}\right) \times (\$33{,}516 - \$8{,}127)\right] + \$8{,}127 = \$29{,}284.50$$

Finally, the accident cost was determined by interpolating between the two preceding accident costs at a length of 400 ft (121.9 m). The calculation was done as follows:

$$AccCost = \left[\left(\frac{400ft - 200ft}{800ft - 200ft}\right) \times (\$29{,}284.50 - \$5{,}407.50)\right] + \$5{,}407.50$$

$$= \$13{,}366.50$$

From BCAFP, b = 0.212 and the accident cost was \$13,351.04 per year.

9.5.3 Example 3 – Rural Arterial

Given:

- Divided
- 3:1 slope
- ADT = 12,000 vpd
- Degree of Curvature = 0 degrees
- Grade = 6 percent
- Length of Feature = 800 ft (243.8 m)
- Height of Feature = 7 ft (2.1 m)
- Offset of Feature from the Edge of the Traveled Way = 2 ft (0.6 m)

The b coefficient was taken from Appendix E and was 1.133. No interpolation was required in this example. Equation 22 was used to calculate the accident cost.

$$AccCost = 12{,}000 \times 1.133 = \$13{,}596$$

From BCAFP, the coefficient was the same but carried out to a higher degree of precision, and the accident cost was $13,597.63 per year. Again, the slight difference in the results was due to rounding errors.

9.5.4 Example 4 – Urban Local

Given:

- 3:1 slope
- ADT = 300 vpd
- Degree of Curvature = 3 degrees
- Grade = 0 percent
- Length of Feature = 1400 ft (426.7 m)
- Height of Feature = 13 ft (4.0 m)
- Offset of Feature from the Edge of the Traveled Way = 2 ft (0.6 m)

The b-coefficient was taken from Appendix I. No interpolation was required in this example; therefore, the coefficient was b = 2.117. For urban local highways, Equation 22 was used to calculate the accident cost.

$$AccCost = 2.117 \times 300 = \$635.10$$

From BCAFP, the b coefficient was the same but carried out to a higher degree of precision, and the accident cost was $635.14 per year. Again, the slight difference in the results was due to rounding errors.

9.5.5 Example 5 – Urban Arterial Highway

Given:

- Undivided
- Guardrail System

- ADT = 12,000 vpd
- Degree of Curvature = 0 degrees
- Grade = 3 percent
- Length of Feature = 800 ft (243.8 m)
- Height of Feature = 7 ft (2.1 m)
- Offset of Feature from the Edge of the Traveled Way = 7 ft (2.1 m)

The b-coefficient was taken from Appendix AA. No interpolation was required in this example; therefore, the coefficient was b = 1.213. Equation 22 was used to calculate the accident cost.

$$AccCost = 12{,}000 \times 1.213 = \$14{,}556$$

From BCAFP, the coefficient was the same but carried out to a higher degree of precision, and the Accident Cost was $14,555.93 per year. Again, the slight difference in the results was due to rounding errors.

10 BENEFIT-COST RATIOS

10.1 B/C Ratios Defined

The incremental B/C ratio compares one alternative to another. Theoretically, a B/C ratio of 1 means that the cost to install a new design is approximately the same as the accident costs associated with the original design. It is usually recommended that a B/C ratio of at least 1.5 be used, but most state departments prefer nothing less than 2.0; therefore, the minimum B/C ratio that would suggest a beneficial design is 2.0. This ratio is obtained from the direct costs and accident costs of each alternative (see Chapters 8 and 9). It is calculated using Equation 23 [6].

$$B/C_{2-1} = \frac{(AC_1 - AC_2)}{(DC_2 - DC_1)} \tag{23}$$

Where

B/C_{2-1} = Incremental B/C ratio of Alternative 2 compared to Alternative 1

AC_1 = Annualized accident cost of Alternative 1

AC_2 = Annualized accident cost of Alternative 2

DC_1 = Annualized direct cost of Alternative 1

DC_2 = Annualized direct cost of Alternative 2

A B/C matrix compares the cost-effectiveness of each alternative under review to all the other alternatives, including the baseline alternative. A sample B/C matrix is given in Figure 21. In general, the alternatives were ordered from left to right and top to bottom based on the direct costs, with the least expensive ("do-nothing") on the left and at the top. The last term in the top row, Guardrail, represented the alternative requiring a TL-3 guardrail system be installed in front of the existing slope. To interpret the results, the engineer can start reading the table in the lower right corner. If this value was greater than 2.0, then Guardrail was better than 6:1. Then, if the next value from the bottom in the last column is greater than 2.0, Guardrail was better than 4:1. This process was continued until either it was determined that Guardrail was better than all alternatives or it was determined that Guardrail was not as beneficial as an alternative. In the sample included, the B/C ratio comparing GR2 to 6:1 was -27.223 meaning that 6:1 was better than Guardrail. It should be noted that negative B/C ratios indicate that the alternative design actually increases the accident cost. From this point forward, the Guardrail option was no longer considered. Then, 6:1 was compared to 4:1 resulting in a B/C ratio of 1.544. Although this is positive and greater than 1, it fails to meet the minimum B/C ratio of 2.0. The modification of the existing slope to 6:1 slope was not considered any further. Next, 4:1 was compared to 3:1, and the ratio was 5.636 which was larger than 2.0. As a result, the slope 3:1 was eliminated from further consideration. Finally, 4:1 was compared to 2:1, the "do-nothing" condition. The ratio was 7.916. For the condition given in the figure caption, the most cost-beneficial option was to install a 4:1 slope. This method allows the engineer to compare different design alternatives directly to one another rather than indirectly by comparing each alternative to the baseline alternative only. Although the 3:1 alternative appears to be the most beneficial, indirectly, it was shown that the 4:1 was the best overall selection because its accident cost reduction was larger relative to the accident cost reduction of the 3:1 slope.

	1V:2H	1V:3H	1V:4H	1V:6H	Guardrail
1V:2H	0	10.195	7.916	4.730	-4.618
1V:3H		0	5.636	2.908	-20.702
1V:4H			0	1.544	-24.210
1V:6H				0	-27.223

Figure 21. Rural Local, Straight, Flat, 200 ft Long, 1 ft High, 2 ft Offset, ADT = 1000

An alternative method of interpretation would be to simply read the largest value from the top row and choose that alternative. In the example shown in Figure 21 that would be the 3:1 slope, with a B/C ratio of 10.195 compared to the “do-nothing” slope.

Although the 3:1, 4:1, and the 6:1 slope alternatives are all beneficial relative to the baseline slope of 2:1, the best option is the 4:1 as determined by interpreting the full matrix. Whenever possible, as many alternatives as are feasible should be investigated and compared using the results of this report and contractor bids on materials and labor for the construction of the alternatives. This will ensure that the selected alternative provides the best balance between safety performance and cost.

10.2 Example Calculation

Determine the most cost-beneficial design alternative from slope flattening options and a guardrail option for a freeway with an existing slope of 3:1.

Given:

- Freeway
- Design Speed = 55 mph (88.5 km/h)
- Existing slope is a 3:1
- ADT = 65,000 vpd
- Degree of Curvature = 0 degrees
- Grade = 2 percent
- Length of Feature = 200 ft (61.0 m)
- Height of Feature = 13 ft (4.0 m)
- Offset of Feature from the Edge of the Traveled Way = 7 ft (2.1 m)
- Assume no additional clear zone is needed for ROW

- Minimum B/C Ratio = 4.0

Solution:

Determine the direct costs as per Chapter 8. Assume the cost per cubic yard of fill is \$30, and the cost of right-of-way (ROW) is \$5 per square foot. To conduct an accurate benefit-cost analysis, these values would need to be determined for every scenario as the costs of fill and ROW vary across a wide range. Assume the shrinkage factor for the volume of borrow soil is zero. Using Equation 14, the required volume for slopes of 4:1 and 6:1 were estimated.

$$V_{1V:4H} = \frac{1}{2}h^2 l(X_{II} - X_I) = \frac{1}{2}(13ft)^2(200ft)(4-3) \times \left(\frac{1\ CY}{27\ ft^3}\right) = 625.93\ CY$$

$$V_{1V:6H} = \frac{1}{2}h^2 l(X_{II} - X_I) = \frac{1}{2}(13ft)^2(200ft)(6-3) \times \left(\frac{1\ CY}{27\ ft^3}\right) = 1{,}877.78\ CY$$

The ROW area was determined using the width of the baseline foreslope and the alternative foreslope, which was a function of the slope and the height. The width was the height multiplied by the slope, where the slope was defined by the horizontal component. For example, the slope of a 4:1 foreslope is 4. In this example, the height was 13 ft (2.1 m). Therefore, the widths of the two alternatives were 52 and 78 ft (15.8 and 23.8 m). The width of the baseline alternative was 39 ft (11.9 m). The net width of the required ROW was the difference between the width of the alternative slope and the baseline slope. The area was then determined by multiplying the net width by the length of the foreslope, or in this case, 200 ft (61.0 m).

The direct cost of each alternative was calculated using Equation 19. The resulting volumes, square footages of ROW, and associated costs are given in Table 18. It should be noted that the direct cost of the baseline slope was \$0.00.

$$DC_{1V:4H} = P \cdot \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] = 148{,}777.78 \cdot \left[\frac{0.04(1+0.04)^{25}}{(1+0.04)^{25} - 1}\right] = \$9{,}521.78$$

$$DC_{1V:6H} = P \cdot \left[\frac{i(1+i)^n}{(1+i)^n-1}\right] = 446{,}333.33 \cdot \left[\frac{0.04(1+0.04)^{25}}{(1+0.04)^{25}-1}\right] = \$28{,}565.33$$

Table 18. Direct Cost Calculations

Slope (1V:XH)	Volume (yard^3)	Fill Cost ($)	ROW area (ft^2)	ROW Cost ($)	Total Cost ($)	Direct Cost ($)
1V:4H	625.93	18777.78	2600	13000	31777.78	2033.78
1V:6H	1877.78	56333.33	7800	39000	95333.33	6101.33

Next, the accident costs associated with the given scenario for all three slopes must be determined. For the 3:1 slope, BCAFP calculates the accident cost to be $27,545.28. For the 4:1 slope, BCAFP calculates the accident cost to be $20,171.21 For the 6:1 slope, BCAFP calculates the accident cost to be $2,579.61. The B/C ratios were calculated using Equation 23.

$$B/C_{4-3} = \frac{(27545.28-20171.21)}{(2033.78-0)} = 3.63$$

$$B/C_{6-3} = \frac{(27545.28-2579.61)}{(6101.33-0)} = 4.09$$

$$B/C_{6-4} = \frac{(20171.21-2579.61)}{(6101.33-2033.78)} = 4.32$$

Next, the accident cost and direct cost of the Guardrail option was determined. The total length of material of the guardrail can be estimated using the Roadside Design Guide or Section 8.2 of this report. The total length would be approximately 550 feet with two end terminals. The value was arrived at by using Equations 17 and 18.

$$L = 2 \cdot (x - L_1 - 37.5) + l \qquad (17)$$

$$x = \frac{(H \cdot S)+(L_1 \cdot F)}{F+\left(\frac{H \cdot S+L_2}{L_R}\right)} \qquad (18)$$

Where L_1 was assumed to be 25 ft (7.6 m) and provided a buffer region between the end of the tangent section of guardrail and the beginning of the foreslope. The length, *l*, was 200 ft (61.0 m), or the length of the foreslope. The height, H, the foreslope, was 13 ft (4.0 m). The slope, S, of the foreslope was 3. The flare rate, F, was the flare rate of the ends of the guardrail and the terminal. This value was chosen from the RDG to be 24:1 and was because the shy line was 7.2 ft (2.2 m) for a 55-mph (88.5 km/h) design speed. This meant that the barrier would be located within the shy line. For use in Equation 18, F was converted to a decimal and was 0.04167 (1/24). The offset distance to the face of the guardrail, L_2, was 7 ft (2.1 m). Finally, the runout length, L_R, was determined by Table 5.8 in the 2006 RDG [2]. This value was 360 ft (109.7 m). It should be noted that the slope is protected from both directions equally, providing a conservative length-of-need.

$$x = \frac{(13\cdot 3)+(25\cdot 0.04167)}{0.04167+\left(\frac{13\cdot 3+7}{360}\right)} = 236.31\,ft$$

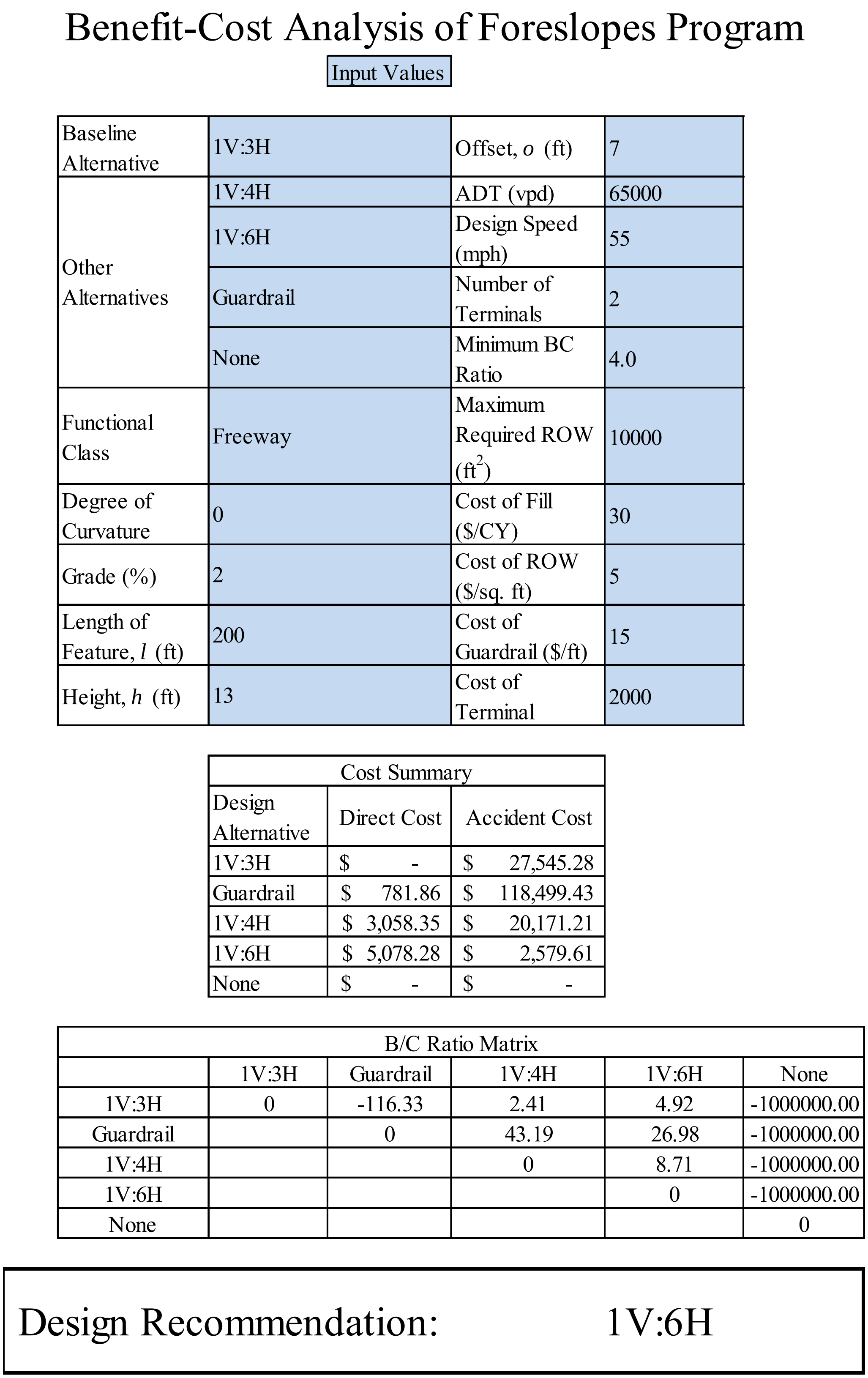
$$L = 2\cdot(236.31-25-37.5)+200 = 547.61\,ft = 550\,ft$$

The cost per foot of guardrail was \$15 per foot while the cost per terminal was \$2,000 [30]. The total installation cost would be \$12,250 but the direct cost (assuming 4 percent interest and 25-year design life) would be \$784.00 per year. For a guardrail system, BCAFP calculates the accident cost to be \$781.86. This value includes the length-of-need of 550 ft (167.6 m) for the 200-ft (60.1 m) feature length; therefore, the accident cost is \$118,499.43 per year.

$$B/C_{GR-3} = \frac{(27545.28-118499.43)}{(781.86)} = -116.33$$

Therefore, even though the installation cost of the Guardrail option was greatly reduced, the accident cost was higher than the original unprotected slope. This caused the

B/C ratio to be negative. In addition, the 4:1 and 6:1 slopes had large B/C ratios compared to the Guardrail option, making any one of the slope flattening options more cost-effective than the Guardrail option, in this example. The engineer would be justified in recommending that the existing slope be flattened to 6:1. This recommendation is illustrated by the tabulated B/C ratios shown in Figure 22. This figure was directly taken from BCAFP, in which a fifth alternative, "None," is a placeholder in the event that a fifth alternative is used. Because the 6:1 to 4:1 ratio is 8.71, the 4:1 slope would be dropped from further consideration. Then, because the 6:1 to Guardrail ratio is 26.98, the Guardrail option would also be dropped from further consideration. Finally, because the 6:1 to 3:1 (baseline) ratio is 4.92, the 6:1 slope would be recommended (i.e., B/C ≥ 4.0).



Benefit-Cost Analysis of Foreslopes Program

Input Values

Baseline Alternative	1V:3H	Offset, *o* (ft)	7
Other Alternatives	1V:4H	ADT (vpd)	65000
	1V:6H	Design Speed (mph)	55
	Guardrail	Number of Terminals	2
	None	Minimum BC Ratio	4.0
Functional Class	Freeway	Maximum Required ROW (ft^2)	10000
Degree of Curvature	0	Cost of Fill ($/CY)	30
Grade (%)	2	Cost of ROW ($/sq. ft)	5
Length of Feature, *l* (ft)	200	Cost of Guardrail ($/ft)	15
Height, *h* (ft)	13	Cost of Terminal	2000

Cost Summary

Design Alternative	Direct Cost	Accident Cost
1V:3H	$ -	$ 27,545.28
Guardrail	$ 781.86	$ 118,499.43
1V:4H	$ 3,058.35	$ 20,171.21
1V:6H	$ 5,078.28	$ 2,579.61
None	$ -	$ -

B/C Ratio Matrix

	1V:3H	Guardrail	1V:4H	1V:6H	None
1V:3H	0	-116.33	2.41	4.92	-1000000.00
Guardrail		0	43.19	26.98	-1000000.00
1V:4H			0	8.71	-1000000.00
1V:6H				0	-1000000.00
None					0

Design Recommendation: 1V:6H

Figure 22. BCAFP "BC Analysis" Sheet

11 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

11.1 Summary

Based on accident data collected in 2000 in the State of Ohio, the severity indexes on selected foreslopes were estimated. This was done by associating the number of (K+A) accidents with the total mileage for each slope-height combination. In each combination, the severity index was reduced, relative to Wolford's results and the default results in RSAP (version 2003.04.01). This was shown graphically for an embankment height of 7 ft (2.1 m) in Figures 6 and 7. This reduction was expected based on comments made in the RSAP Engineer's Manual that stated severity indexes were likely biased towards higher-speed impacts.

Once the new severity indexes for foreslopes were determined, they were implemented into RSAP and used in the simulation of the extensive test matrix. Each scenario in the test matrix was repeated for several traffic volumes. For each scenario and traffic volume, RSAP estimated an accident cost. From these accident costs, equations were developed to determine linear relationships between the volumes and the accident costs. These equations were described by a series of coefficients and were in the slope-intercept form. For each scenario, these coefficients are presented in the attached appendices. Based on the functional class and the traffic volume, an applicable equation could be chosen from Section 9.2. With the coefficients and the traffic volume, the accident cost for any scenario can be calculated. In addition, a Microsoft Excel program known as BCAFP was developed to automatically lookup those coefficients and interpolate or extrapolate when needed. This program greatly reduced the time and effort needed to determined the accident costs and B/C ratios, and it removed the possibility of human error in both looking up values and in making calculation mistakes during interpolation or extrapolation.

Finally, the benefit-cost application of these accident costs was described. The difference in accident costs between two competing alternatives represents the numerator of the B/C ratio, which can be used to justify the use of one design alternative over another. In order to successfully complete the benefit-cost analysis, the engineer must ascertain the material costs of each alternative under consideration in order to construct the denominator of the B/C ratio. An example of this process was given in Section 10.2.

11.2 Conclusions

Severity indexes used in the default version of RSAP were overestimated. This report has presented new severity indexes and used them to determined accident costs on an array of different foreslopes. Once the results of the RSAP analysis were available, trends appeared in each of the parameters and for each of the functional classes. Flattening the slope and increasing the offset decreased the accident costs for all functional classes. Likewise, increasing the traffic volume and length of the feature increased the accident costs for all functional classes. The degree of curvature and the percent grade caused initial decreases in accident costs (however slight they were), but then increased accident costs as those parameters continued to increase. As the height of the feature increased, the accident cost tended to increase as well. However, this increase was not as significant as the increase caused by the traffic volume and the length of the feature. Finally, and of most importance, slope flattening dramatically reduced accident costs. On short embankment heights, the largest decrease in accident costs on adjacent slopes occurred when a 3:1 foreslope was flattened to a 4:1 foreslope, which reduced the accident cost by approximately 80 percent, but when the slope was flattened from a 4:1

foreslope to a 6:1 foreslope, the reduction was approximately 50 percent. On medium and tall heights, that trend was exactly reversed. Therefore, the increased severity on steep, tall embankments may warrant slope flattening beyond 4:1. Additionally, no matter what functional class was considered, flattening to a 6:1 slope provided the largest overall reduction in accident costs. This does not necessarily mean that the 6:1 slope was the best alternative, as direct costs need to be included in the analysis before the best alternative can be chosen.

Finally, as illustrated in the decision tree in Figure 9, guardrail systems should only be considered after all possible slope flattening alternatives have been explored. The trends in Figure 14 through Figure 20 show an extreme increase in accident cost for the guardrail system relative to the foreslopes. Guardrail systems may only be applicable in areas where slope flattening cannot be accomplished, either because of urban settings or because of some other limiting factor.

11.3 Recommendations for Application

The severity index is directly proportional to the impact speed. As a result, the severity indexes were determined for several impact speeds such that a linear equation could be developed from the results. For each slope-height combination, the linear equation is presented in Table 19. In the equations, SI represents the severity index and v represents the impact speed in terms of miles per hour (mph). These severity index equations should be used when estimating accident costs of crashes involving clear foreslopes.

Table 19. Severity Index Equations Based on Impact Speed

Slope-Height Combination	SI Equation
6:1, $H \geq 1$ ft (0.3 m)	$SI = 0.0181 \cdot v$
4:1, $H = 1$ ft (0.3 m)	$SI = 0.0186 \cdot v$
4:1, $H \geq 7$ ft (2.1 m)	$SI = 0.0366 \cdot v$
3:1, $H = 1$ ft (0.3 m)	$SI = 0.0360 \cdot v$
3:1, $H = 7$ ft (2.1 m)	$SI = 0.0400 \cdot v$
3:1, $H = 13$ ft (4.0 m)	$SI = 0.0429 \cdot v$
2:1, $H = 1$ ft (0.3 m)	$SI = 0.0415 \cdot v$
2:1, $H = 7$ ft (2.1 m)	$SI = 0.0458 \cdot v$
2:1, $H = 13$ ft (4.0 m)	$SI = 0.0486 \cdot v$

11.4 Recommendations for Future Work

There is significant room for improvement beyond this report. A larger sample size would provide more consistent results for both the 6:1 slope and the tall heights for all slopes. It would also lend more credibility to the results of the remaining slopes and heights. Also, traffic volumes could be included in the analysis to negate the influence of increased exposure on some highways. With larger volumes, the number of (K+A) accidents would increase over the same length of highway, which in turn would increase the average severity. The same procedure outlined in this report would be used on slope-height-volume combinations. Then, each volume would be normalized about some constant traffic volume, which could be programmed into RSAP. The final result would give the number of (K+A) accidents per mile per unit of traffic volume.

A more detailed investigation into the effects of barrier warrants on the number of (K+A) accidents for steep, tall embankments needs to be conducted. The work done in this thesis was partially based on an extrapolation done to estimate the number of (K+A) accidents on tall embankments, especially for the 2:1 foreslope. If barrier warrants investigation can successfully estimate the number of miles of unprotected, steep, tall embankments, then the number of (K+A) accidents per mile of that foreslope would actually be indicative of the severity.

Additionally, the current version of RSAP assumes a straight-line encroachment path. As a result, the driver behavior is not considered. Drivers are more likely to attempt a corrective maneuver when the vehicle is encroaching on a foreslope than they are to continue in a straight line. This corrective maneuver would increase the propensity for rollover; however, RSAP does not incorporate rollover into the calculation of the average severity index of a foreslope. It was assumed that the effect of rollover on the average accident cost was offset by increasing the SI, but this increase was not based on any data pertaining to accident costs of rollovers, but rather engineering judgment. RSAP is currently being updated under NCHRP Project No. 22-27 and will include curvi-linear encroachment paths [16]. Once this update is complete, the number of (K+A) accidents can be recalibrated against the accident data to estimate severity indexes that are based on encroachments that are allowed to follow more natural paths.

12 LIMITATIONS

12.1 Severity Index Updates

Results of this analysis were highly dependent on the severity index used to estimate the accident cost of each scenario. Therefore, part of this study focused on developing more accurate severity indexes on foreslopes. This part provided the major limitations to this study.

The number of (K+A) accidents can be significantly influenced by the traffic volume. The average severity is determined only after all possible scenarios have been simulated. That is, the damage caused by the severe accidents was divided by the total number of impacts to calculate an average severity for all impacts. If the traffic volume increases, the probability of severe accidents increases, which ultimately would increase the severity index. This is because the severity index is non-linear with its associated societal costs. The more severe accidents have a larger influence than the less severe accidents. So, even if the difference in the number of severe and non-severe accidents does not change, the severity index will either increase or decrease, depending on how the traffic volume changes. However, this could not be accounted for in this project because the traffic volume at the accident locations and at the random sample locations was unknown. If the traffic volume was known over the entire highway network (e.g. at every 100-ft (30.5-m) interval), then slope-height-volume combinations could be constructed and the mileage for each one could be determined. As before, the number of (K+A) accidents would be counted for each combination. Then, the results would be normalized with respect to a unit of traffic volume, say 10,000 vehicles per day. This traffic volume would be entered into RSAP much in the same way as the length of the feature was entered (recall the length was set to 1 mile so that the number of (K+A) accidents was already given in a per-mile format).

Another limitation to this work is the small sample size used to develop the new severity indexes. Only 1,296 accidents were analyzed, which was small compared to Wolford's work, which included more than 20,000 accidents. Also, only one year was used in the data collection. It was the first year of data supplied by Ohio. In addition to that year (2000), data for every year through 2006 was supplied, but time restraints prevented the complete analysis of all this data. Also, the number of accidents from the year 2000 was significantly smaller than in each subsequent year. This may be due to a new data entry system or some change in policy regarding accident reports, however, this is not known.

A limitation related to the small sample size was in the determination of the expected number of (K+A) accidents on a 6:1 slope. No severe accidents occurred on heights less than 13 ft (4.0 m). Because the expected number of severe accidents for the other slopes was determined by the short and medium heights, the number of expected severe accidents on a 6:1 slope was set to zero. However, there were severe accidents on 6:1 slopes, according to the actual accident data. As a result, the SI values of this slope should be higher than what are presented in this paper. With the addition or more data, this conclusion should be supported and this limitation should be eliminated.

Impact speed also plays a pivotal role in the determination of the SI value for a given roadside feature. However, the accident data set could not include exact impact speeds. Only estimations were given and were most likely based on human judgment. The average impact speed from the accident data was 53.9 mph (86.7 km/h). Based on research done at the Midwest Roadside Safety Facility, the average impact speed on a US and State route is approximately 39 mph (62.8 km/h). As a result, the impact velocities given in the accident data was too high and unusable. If actual impact speeds were known, the relationship between the impact speed and the SI could be checked. Initially, this relationship was assumed to be linear. However, there may be reason to suspect that this relationship is more parabolic, considering the relationship between kinetic energy and velocity, which is commonly used to describe severities of impacts with barriers.

12.2 RSAP Programming For the Current Version (2003.04.01)

12.2.1 Conceptual Limitations

Encroachment paths are assumed to be linear in the current version of RSAP. This disallows the possibility of overcorrection as the motorists reacts to the unexpected encroachment. An overcorrection could potentially increase the rate of rollover on foreslopes substantially, which in turn, would increase severity indexes. Work is being done on a new version of RSAP that uses set vehicular encroachment paths, which include curved paths, as opposed to straight-line paths whose angles are determined by Monte Carlo simulation [16]. This may increase the accuracy associated with foreslopes as they are related to rollover incidents. RSAP currently employs a rollover prediction algorithm that is applied to fixed objects only. However, as much as 86 percent of all rollovers occur on roadside features that do not include these objects [15]. Instead, RSAP attempts to account for these rollovers by increasing severity indexes for the associated feature, such as a foreslope [6].

RSAP uses speed distributions for various functional classes that were based on a study done before the national speed limit was lifted [33]. In order to predict encroachment speeds indicative of today’s traffic, a new study should be undertaken following the same procedures used by Mak, Sicking, and Ross to determine speed distributions without the influence of the national speed limit.

Cross-median crashes are not simulated explicitly. This approach may have a profound effect on the results of a B/C analysis because these crashes are typically severe. If a vehicle has encroached that far, a possible reason may be that the driver is already unconscious (for example). In this event, the impact speed and angle may also be severe. Striking a fixed object under these conditions could be worse than a typical impact with a fixed object, provided the driver has time to break in the latter event before striking the object. Also, head-on collisions are completely ignored because RSAP assumes one vehicle at a time per simulation. Obviously the benefit of a median barrier would be greatly underestimated if one of these head-on collisions were possible.

Finally, access density is not considered in RSAP. These access points would include on and off ramps on interstates. It is these locations that experience the greatest crash frequency. This increased frequency is in part due to the changes in driver interactions, as vehicles are added to or removed from the roadway (recall that only one vehicle is simulated).

12.2.2 Cooper Data

Cooper used a statistical design that was dependent on the outcome. In other words, bias was introduced into the data set. This had the tendency to inflate extreme events (e.g. high and low encroachment rates were made higher and lower). However, the extent of this bias was and remains unknown.

The results of Cooper's data showed a similar relationship between ADT and encroachment frequency as Hutchinson and Kennedy's data showed. However, the latter study's encroachment rate was shown to be influenced by seasonal effects more than the traffic volume [13]. This reanalysis of the classic study had not been performed on the Cooper data yet but needs to be done to determine if traffic volume alone can be used to describe the encroachment frequency.

Also, the data was collected in the late 1970s. Technological and mathematical breakthroughs had not yet been achieved that would have allowed the author to collect and analyze the data in a better way. With a wider network of traffic cameras, perhaps more encroachment data could have been taken. Also, at the time of the report, Cooper’s statistical approach was based on the relatively new concept of clustering. It was this approach that ultimately led to the bias previously mentioned. Today’s clustering approach is used in studies like the Census, in which statistical tools have been developed that can handle clustered data.

No distinction was made in the data set between controlled and uncontrolled encroachments. This distinction could not be made either, because the intent of the driver was impossible to determine. Controlled encroachments could include pulling over to switch drivers, among many other possibilities. Attempts have been made to estimate the number of controlled verses uncontrolled accidents for various roadside features, but applying this ratio to the Cooper data, as RSAP does, needs investigated further. Unfortunately, due to the enormous cost that would be associated with a study to ascertain the intent behind each encroachment, the current practice utilized by RSAP will have to suffice.

Finally, the small sample size of the Cooper data was a concern. The intent of that study was to increase the sample size by creating smaller segments of the highway. However, this also reduced the number of encroachments per segment, which statistically did nothing to improve the results of the analysis. Only when additional segments are studied and/or the time included in the data collection is extended will the sample size be increased, which can only lend stability to the statistical results.

12.2.3 Discrepancies, Bugs, and Errors

Since the completion of the RSAP code, several problems have been discovered. Because the code is very large, it remains possible that more problems exist. Currently known problems include discrepancies between what is coded and what is mentioned in the Engineer's Manual, bugs, and errors. Bugs are caused by programming errors relative to the language used. Errors are mistakes in the code that lead to incorrect results. All three of these problems have been found in the current code. In an ongoing project intended to update RSAP, Dr. Malcolm Ray and his research team have discovered many of these errors. They are outlined in the draft report of that project (NCHRP Project 22-27) [16]. The problems are only listed here. For a more detailed description of the problems, see the draft report of NCHRP Project 22-27.

12.2.3.1 Discrepancies

- Base encroachment rates for two-lane undivided and multi-lane divided highways do not have the same adjustment factor in the code as are presented in the Engineer's Manual.
- Lane encroachment rates are equal for all lanes despite unequal traffic volume distributions, which should indicate differing encroachment rates as demonstrated by the Cooper data.
- The probability of the lateral extent of encroachment uses a cubic function instead of the correct exponential function. As a result, the probability may be negative for extents greater than 22 m. These negative probabilities are then forced to zero; however, the exponential function would indicate a positive probability.

- The traffic growth factor in the code increases the ADT each year and adjusts the encroachment frequency accordingly. The Engineer’s Manual says it increases in only one increment, at the time of the design life. In this discrepancy alone, the code appears to be more accurate than the Engineer’s Manual.

12.2.3.2 Bugs or Errors

- Base encroachment rates are not reduced to 60 percent for the effect of unreported accidents on two-lane undivided and one-way highways.
- The traffic growth factor is divided by 100 to get a decimal form of the percentage. It is then divided by 100 again by mistake when determining the encroachment frequency.
- Highway types are distinguished between undivided, divided, and one-way highways; however, RSAP appears to change how these categories are referenced. It is possible that the highway type is incorrectly chosen.
- Curvature adjustments in the vehicle swath equations convert the degrees to a radius in units of 100-ft stations; however, that radius is used as if it were in units of 100-m stations. This problem is only applicable to the user interface. If the radius of curvature is specified in the data files, the conversion from radius to degree is correct. The original code was in US units but was converted to SI units. Due to the large size of the code, it is possible that more unit conversion errors exist.
- Lane encroachment rates are approximately half of what they should be for two-lane undivided highways.

13 NOTATION

*All notations are given in alphabetical order.

#K+A = Number of fatal and severe injury accidents
1V:XH = Slope designation describing a foreslope
A = Area of the cross-section of the new slope
A = Severe injury
AC = Annualized accident cost
AccCost = Accident cost
ADT = Traffic volume in vehicles per day (vpd)
A_I = Area of the cross-section of the minimum slope
A_{II} = Area of the cross-section of the new minus the original slope
B = Moderate injury
b = Slope of the equation to determine *AccCost* for freeways and local highways as well as arterials with small ADTs
B/C_{2-1} = Incremental benefit/cost ratio of alternative 2 compared to alternative 1
b_1 = Base of the cross-sectional area of the minimum slope
b_2 = Base of the cross-sectional area of the new slope
C = Slight injury
c = Slope of the equation to determine *AccCost* for large traffic volumes on rural arterial highways and intermediate traffic volumes on urban arterial highways
d = Y-axis intercept of the equation to determine *AccCost* for large traffic volumes on rural arterial highways and intermediate traffic volumes on urban arterial highways
DC = Annualized direct cost
e = Slope of the equation to determine *AccCost* for large traffic volumes on urban arterial highways
F = Flare rate of the guardrail
f = Y-axis intercept of the equation to determine *AccCost* for large traffic volumes on urban arterial highways
h = Height of the foreslope
H = Height of the foreslope
i = Interest rate
K = Fatality
l = Length of the foreslope
L = Total length of guardrail required
L_1 = Buffer length of guardrail = 25 ft (7.6 m)
L_2 = Offset of the guardrail
L_R = Runout length

n = Design life
O = Property damage only (PDO)
P = Principal investment required for construction
S = Horizontal component of the foreslope designation (S = X in the form 1V:XH)
SI = Severity index
t = Time between Consumer Price Index readings, 1994 to 2009 = 15 years
V_{borrow} = Volume of borrowed soil required to meet V_{fill} demand
V_{fill} = Volume of fill required to flatten the slope
x = Length of guardrail required beyond the 25-ft (7.6-m) buffer
X_I = Slope of the baseline foreslope (1V:X_IH)
X_{II} = Slope of the baseline foreslope (1V:X_{II}H)
φ_2 = Accident rate equation for 2:1 slopes
φ_3 = Accident rate equation for 3:1 slopes
φ_4 = Accident rate equation for 4:1 slopes
$(\bar{\gamma}_d)_c$ = Average dry unit weight of borrow soil
$(\bar{\gamma}_d)_f$ = Average dry unit weight of fill soil
$\frac{\Delta V}{V_f}$ = Shrinkage factor applied to borrow soil

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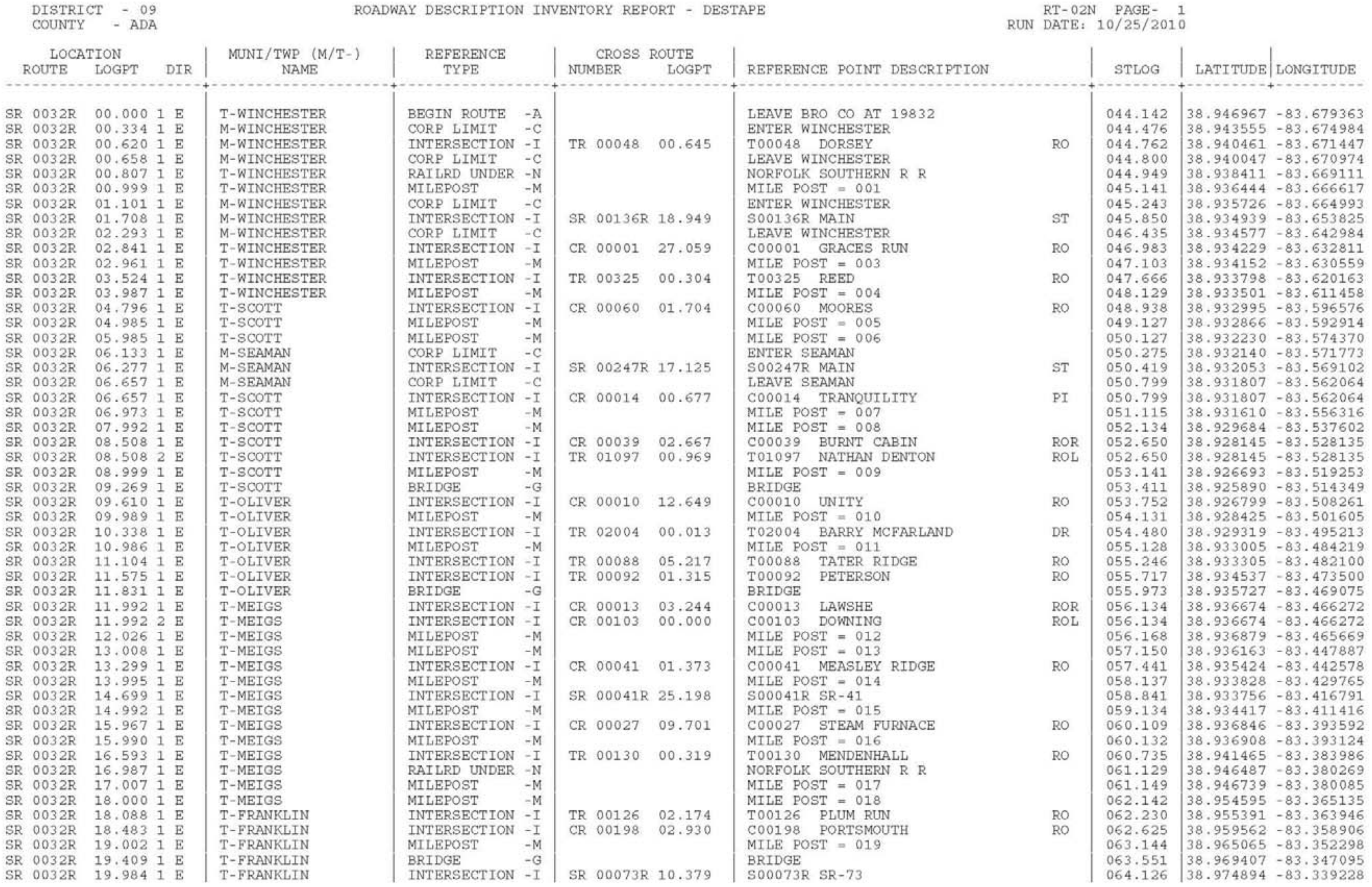
15 APPENDICES

Appendix A. Roadway Description Inventory Example



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DISTRICT  - 09                  ROADWAY DESCRIPTION INVENTORY REPORT - DESTAPE                           RT-02N  PAGE-  1
COUNTY   - ADA                                                                                       RUN DATE: 10/25/2010

   LOCATION            | MUNI/TWP (M/T-)  |   REFERENCE     |   CROSS ROUTE      |                                       |           |         |
 ROUTE   LOGPT   DIR   |      NAME        |     TYPE        | NUMBER      LOGPT  | REFERENCE POINT DESCRIPTION           |   STLOG   | LATITUDE|LONGITUDE
-----------------------+------------------+-----------------+--------------------+---------------------------------------+-----------+---------+----------

SR 0032R  00.000 1 E   | T-WINCHESTER     | BEGIN ROUTE  -A |                    | LEAVE BRO CO AT 19832                 |  044.142  |38.946967 -83.679363
SR 0032R  00.334 1 E   | M-WINCHESTER     | CORP LIMIT   -C |                    | ENTER WINCHESTER                      |  044.476  |38.943555 -83.674984
SR 0032R  00.620 1 E   | M-WINCHESTER     | INTERSECTION -I | TR 00048   00.645  | T00048  DORSEY                    RO  |  044.762  |38.940461 -83.671447
SR 0032R  00.658 1 E   | M-WINCHESTER     | CORP LIMIT   -C |                    | LEAVE WINCHESTER                      |  044.800  |38.940047 -83.670974
SR 0032R  00.807 1 E   | T-WINCHESTER     | RAILRD UNDER -N |                    | NORFOLK SOUTHERN R R                  |  044.949  |38.938411 -83.669111
SR 0032R  00.999 1 E   | T-WINCHESTER     | MILEPOST     -M |                    | MILE POST = 001                       |  045.141  |38.936444 -83.666617
SR 0032R  01.101 1 E   | M-WINCHESTER     | CORP LIMIT   -C |                    | ENTER WINCHESTER                      |  045.243  |38.935726 -83.664993
SR 0032R  01.708 1 E   | M-WINCHESTER     | INTERSECTION -I | SR 00136R 18.949   | S00136R MAIN                      ST  |  045.850  |38.934939 -83.653825
SR 0032R  02.293 1 E   | M-WINCHESTER     | CORP LIMIT   -C |                    | LEAVE WINCHESTER                      |  046.435  |38.934577 -83.642984
SR 0032R  02.841 1 E   | T-WINCHESTER     | INTERSECTION -I | CR 00001   27.059  | C00001  GRACES RUN                RO  |  046.983  |38.934229 -83.632811
SR 0032R  02.961 1 E   | T-WINCHESTER     | MILEPOST     -M |                    | MILE POST = 003                       |  047.103  |38.934152 -83.630559
SR 0032R  03.524 1 E   | T-WINCHESTER     | INTERSECTION -I | TR 00325   00.304  | T00325  REED                      RO  |  047.666  |38.933798 -83.620163
SR 0032R  03.987 1 E   | T-WINCHESTER     | MILEPOST     -M |                    | MILE POST = 004                       |  048.129  |38.933501 -83.611458
SR 0032R  04.796 1 E   | T-SCOTT          | INTERSECTION -I | CR 00060   01.704  | C00060  MOORES                    RO  |  048.938  |38.932995 -83.596576
SR 0032R  04.985 1 E   | T-SCOTT          | MILEPOST     -M |                    | MILE POST = 005                       |  049.127  |38.932866 -83.592914
SR 0032R  05.985 1 E   | T-SCOTT          | MILEPOST     -M |                    | MILE POST = 006                       |  050.127  |38.932230 -83.574370
SR 0032R  06.133 1 E   | M-SEAMAN         | CORP LIMIT   -C |                    | ENTER SEAMAN                          |  050.275  |38.932140 -83.571773
SR 0032R  06.277 1 E   | M-SEAMAN         | INTERSECTION -I | SR 00247R 17.125   | S00247R MAIN                      ST  |  050.419  |38.932053 -83.569102
SR 0032R  06.657 1 E   | M-SEAMAN         | CORP LIMIT   -C |                    | LEAVE SEAMAN                          |  050.799  |38.931807 -83.562064
SR 0032R  06.657 1 E   | T-SCOTT          | INTERSECTION -I | CR 00014   00.677  | C00014  TRANQUILITY               PI  |  050.799  |38.931807 -83.562064
SR 0032R  06.973 1 E   | T-SCOTT          | MILEPOST     -M |                    | MILE POST = 007                       |  051.115  |38.931610 -83.556316
SR 0032R  07.992 1 E   | T-SCOTT          | MILEPOST     -M |                    | MILE POST = 008                       |  052.134  |38.929684 -83.537602
SR 0032R  08.508 1 E   | T-SCOTT          | INTERSECTION -I | CR 00039   02.667  | C00039  BURNT CABIN               ROR |  052.650  |38.928145 -83.528135
SR 0032R  08.508 2 E   | T-SCOTT          | INTERSECTION -I | TR 01097   00.969  | T01097  NATHAN DENTON             ROL |  052.650  |38.928145 -83.528135
SR 0032R  08.999 1 E   | T-SCOTT          | MILEPOST     -M |                    | MILE POST = 009                       |  053.141  |38.926693 -83.519253
SR 0032R  09.269 1 E   | T-SCOTT          | BRIDGE       -G |                    | BRIDGE                                |  053.411  |38.925890 -83.514349
SR 0032R  09.610 1 E   | T-OLIVER         | INTERSECTION -I | CR 00010   12.649  | C00010  UNITY                     RO  |  053.752  |38.926799 -83.508261
SR 0032R  09.989 1 E   | T-OLIVER         | MILEPOST     -M |                    | MILE POST = 010                       |  054.131  |38.928425 -83.501605
SR 0032R  10.338 1 E   | T-OLIVER         | INTERSECTION -I | TR 02004   00.013  | T02004  BARRY MCFARLAND           DR  |  054.480  |38.929319 -83.495213
SR 0032R  10.986 1 E   | T-OLIVER         | MILEPOST     -M |                    | MILE POST = 011                       |  055.128  |38.933005 -83.484219
SR 0032R  11.104 1 E   | T-OLIVER         | INTERSECTION -I | TR 00088   05.217  | T00088  TATER RIDGE               RO  |  055.246  |38.933305 -83.482100
SR 0032R  11.575 1 E   | T-OLIVER         | INTERSECTION -I | TR 00092   01.315  | T00092  PETERSON                  RO  |  055.717  |38.934537 -83.473500
SR 0032R  11.831 1 E   | T-OLIVER         | BRIDGE       -G |                    | BRIDGE                                |  055.973  |38.935727 -83.469075
SR 0032R  11.992 1 E   | T-MEIGS          | INTERSECTION -I | CR 00013   03.244  | C00013  LAWSHE                    ROR |  056.134  |38.936674 -83.466272
SR 0032R  11.992 2 E   | T-MEIGS          | INTERSECTION -I | CR 00103   00.000  | C00103  DOWNING                   ROL |  056.134  |38.936674 -83.466272
SR 0032R  12.026 1 E   | T-MEIGS          | MILEPOST     -M |                    | MILE POST = 012                       |  056.168  |38.936879 -83.465669
SR 0032R  13.008 1 E   | T-MEIGS          | MILEPOST     -M |                    | MILE POST = 013                       |  057.150  |38.936163 -83.447887
SR 0032R  13.299 1 E   | T-MEIGS          | INTERSECTION -I | CR 00041   01.373  | C00041  MEASLEY RIDGE             RO  |  057.441  |38.935424 -83.442578
SR 0032R  13.995 1 E   | T-MEIGS          | MILEPOST     -M |                    | MILE POST = 014                       |  058.137  |38.933828 -83.429765
SR 0032R  14.699 1 E   | T-MEIGS          | INTERSECTION -I | SR 00041R 25.198   | S00041R SR-41                         |  058.841  |38.933756 -83.416791
SR 0032R  14.992 1 E   | T-MEIGS          | MILEPOST     -M |                    | MILE POST = 015                       |  059.134  |38.934417 -83.411416
SR 0032R  15.967 1 E   | T-MEIGS          | INTERSECTION -I | CR 00027   09.701  | C00027  STEAM FURNACE             RO  |  060.109  |38.936846 -83.393592
SR 0032R  15.990 1 E   | T-MEIGS          | MILEPOST     -M |                    | MILE POST = 016                       |  060.132  |38.936908 -83.393124
SR 0032R  16.593 1 E   | T-MEIGS          | INTERSECTION -I | TR 00130   00.319  | T00130  MENDENHALL                RO  |  060.735  |38.941465 -83.383986
SR 0032R  16.987 1 E   | T-MEIGS          | RAILRD UNDER -N |                    | NORFOLK SOUTHERN R R                  |  061.129  |38.946487 -83.380269
SR 0032R  17.007 1 E   | T-MEIGS          | MILEPOST     -M |                    | MILE POST = 017                       |  061.149  |38.946739 -83.380085
SR 0032R  18.000 1 E   | T-MEIGS          | MILEPOST     -M |                    | MILE POST = 018                       |  062.142  |38.954595 -83.365135
SR 0032R  18.088 1 E   | T-FRANKLIN       | INTERSECTION -I | TR 00126   02.174  | T00126  PLUM RUN                  RO  |  062.230  |38.955391 -83.363946
SR 0032R  18.483 1 E   | T-FRANKLIN       | INTERSECTION -I | CR 00198   02.930  | C00198  PORTSMOUTH                RO  |  062.625  |38.959562 -83.358906
SR 0032R  19.002 1 E   | T-FRANKLIN       | MILEPOST     -M |                    | MILE POST = 019                       |  063.144  |38.965065 -83.352298
SR 0032R  19.409 1 E   | T-FRANKLIN       | BRIDGE       -G |                    | BRIDGE                                |  063.551  |38.969407 -83.347095
SR 0032R  19.984 1 E   | T-FRANKLIN       | INTERSECTION -I | SR 00073R 10.379   | S00073R SR-73                         |  064.126  |38.974894 -83.339228
```

Appendix B. 2:1 Rural Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.983
				7	0.639
				12	0.456
			7	2	1.515
				7	1.095
				12	0.780
			13	2	2.044
				7	1.362
				12	0.993
		800	1	2	3.471
				7	2.586
				12	1.781
			7	2	5.342
				7	3.786
				12	2.727
			13	2	6.698
				7	4.835
				12	3.457
		1400	1	2	6.166
				7	4.386
				12	3.115
			7	2	9.212
				7	6.654
				12	4.806
			13	2	11.453
				7	8.203
				12	6.000
	4	200	1	2	1.220
				7	0.820
				12	0.560
			7	2	1.988
				7	1.346
				12	0.941
			13	2	2.475
				7	1.704
				12	1.240
		800	1	2	4.329
				7	3.145
				12	2.224
			7	2	6.664
				7	4.781
				12	3.416

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	4	800	13	2	8.306
				7	6.252
				12	4.251
		1400	1	2	7.637
				7	5.506
				12	3.955
			7	2	11.367
				7	8.432
				12	5.892
			13	2	14.128
				7	10.339
				12	7.324
	8	200	1	2	1.429
				7	1.043
				12	0.681
			7	2	2.346
				7	1.664
				12	1.149
			13	2	3.144
				7	2.083
				12	1.486
		800	1	2	5.321
				7	3.806
				12	2.642
			7	2	7.819
				7	5.698
				12	4.179
			13	2	10.123
				7	7.354
				12	5.124
		1400	1	2	9.002
				7	6.705
				12	4.695
			7	2	13.698
		1400		7	9.904
				12	7.246
			13	2	17.023
				7	12.542
				12	9.021
4	0	200	1	2	1.892
				7	1.303
				12	0.828

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	200	7	2	2.882
				7	1.981
				12	1.319
			13	2	3.507
				7	2.405
				12	1.621
		800	1	2	7.180
				7	5.254
				12	3.714
			7	2	10.902
				7	7.843
				12	5.630
			13	2	13.886
				7	9.991
				12	6.959
		1400	1	2	12.344
				7	8.884
				12	6.397
			7	2	18.405
				7	13.385
				12	9.410
			13	2	23.044
				7	16.403
				12	11.652
	4	200	1	2	2.305
				7	1.543
				12	1.049
			7	2	3.419
				7	2.555
				12	1.653
			13	2	4.442
				7	3.045
				12	2.007
		800	1	2	9.023
				7	6.578
				12	4.676
			7	2	13.794
				7	9.918
				12	7.001
			13	2	16.833
				7	12.079
				12	8.508

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	4	1400	1	2	15.646
				7	11.277
				12	7.988
			7	2	22.983
				7	16.771
				12	11.885
			13	2	28.815
				7	21.200
				12	14.641
	8	200	1	2	2.790
				7	1.894
				12	1.251
			7	2	4.413
				7	3.051
				12	1.964
			13	2	5.396
				7	3.659
				12	2.567
		800	1	2	10.979
				7	7.929
				12	5.547
			7	2	16.282
				7	11.798
				12	8.375
			13	2	20.268
				7	14.621
	8			12	10.043
		1400	1	2	18.569
				7	13.368
				12	9.616
			7	2	27.946
				7	20.218
				12	14.180
			13	2	34.563
				7	25.195
				12	17.919
8	0	200	1	2	2.822
				7	1.788
				12	1.116
			7	2	3.957
				7	2.723
				12	1.662

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	0	200	13	2	5.048
				7	3.200
				12	2.109
		800	1	2	9.589
				7	6.969
				12	4.950
			7	2	14.419
				7	10.483
				12	7.254
			13	2	17.905
				7	12.886
				12	8.971
		1400	1	2	15.397
				7	11.089
				12	7.853
			7	2	23.008
				7	16.720
				12	11.724
			13	2	28.764
				7	20.662
				12	14.382
	4	200	1	2	3.424
			1	7	2.173
				12	1.330
			7	2	5.089
				7	3.304
				12	2.084
			13	2	6.530
				7	4.244
				12	2.743
		800	1	2	12.180
				7	8.277
				12	5.956
			7	2	17.923
				7	12.984
				12	9.096
			13	2	22.292
				7	15.661
				12	10.807
		1400	1	2	19.350
				7	14.128
				12	9.893

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	4	1400	7	2	28.544
				7	20.985
				12	14.841
			13	2	35.638
				7	25.743
				12	18.474
	8	200	1	2	3.208
				7	2.306
				12	1.397
			7	2	5.026
				7	3.366
				12	2.174
			13	2	6.083
				7	4.067
				12	2.554
		800	1	2	12.029
				7	8.712
				12	6.023
			7	2	17.765
				7	12.897
				12	8.811
			13	2	22.891
				7	15.759
				12	11.400
		1400	1	2	19.563
				7	13.908
				12	10.037
			7	2	28.747
				7	21.591
				12	14.725
			13	2	35.396
				7	26.410
				12	17.905

Appendix C. 3:1 Freeway Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.223
				7	0.167
				12	0.135
			7	2	0.374
				7	0.293
				12	0.205
			13	2	0.524
				7	0.429
				12	0.355
		800	1	2	0.855
				7	0.686
				12	0.544
			7	2	1.234
				7	0.978
				12	0.751
			13	2	1.606
				7	1.274
				12	1.055
		1400	1	2	1.502
				7	1.192
				12	0.975
			7	2	2.103
				7	1.674
				12	1.353
			13	2	2.735
				7	2.186
				12	1.785
	2	200	1	2	0.231
				7	0.173
				12	0.138
			7	2	0.384
				7	0.294
				12	0.219
			13	2	0.549
				7	0.424
				12	0.354
		800	1	2	0.866
				7	0.672
				12	0.548
			7	2	1.226
				7	0.983
				12	0.761

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	2	800	13	2	1.633
				7	1.279
				12	1.067
		1400	1	2	1.521
				7	1.171
				12	0.972
			7	2	2.107
				7	1.659
				12	1.357
			13	2	2.660
				7	2.176
				12	1.771
	3	200	1	2	0.246
				7	0.192
				12	0.154
			7	2	0.419
				7	0.321
				12	0.243
			13	2	0.598
				7	0.498
				12	0.411
		800	1	2	0.968
				7	0.790
				12	0.613
			7	2	1.387
				7	1.086
				12	0.848
			13	2	1.872
				7	1.436
				12	1.188
		1400	1	2	1.688
				7	1.333
				12	1.097
			7	2	2.368
				7	1.891
				12	1.520
			13	2	3.028
				7	2.446
				12	1.993
2	0	200	1	2	0.161
				7	0.101
				12	0.072

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
2	0	200	7	2	0.210
				7	0.142
				12	0.096
			13	2	0.277
				7	0.197
				12	0.152
		800	1	2	0.713
				7	0.537
				12	0.427
			7	2	0.940
				7	0.761
				12	0.608
			13	2	1.220
				7	0.948
				12	0.745
		1400	1	2	1.247
				7	0.955
				12	0.768
			7	2	1.680
				7	1.336
				12	1.032
			13	2	2.156
				7	1.686
				12	1.357
	2	200	1	2	0.161
				7	0.099
				12	0.068
			7	2	0.219
				7	0.149
				12	0.104
			13	2	0.296
				7	0.212
				12	0.148
		800	1	2	0.717
				7	0.549
				12	0.427
			7	2	0.969
				7	0.732
				12	0.595
			13	2	1.256
				7	0.937
				12	0.755

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
2	2	1400	1	2	1.246
				7	0.957
				12	0.763
			7	2	1.670
				7	1.315
				12	1.079
			13	2	2.122
				7	1.681
				12	1.345
	3	200	1	2	0.177
				7	0.115
				12	0.075
			7	2	0.243
				7	0.159
				12	0.108
			13	2	0.313
				7	0.230
				12	0.170
		800	1	2	0.807
				7	0.603
				12	0.488
			7	2	1.081
				7	0.839
				12	0.654
			13	2	1.416
				7	1.048
				12	0.878
		1400	1	2	1.398
				7	1.073
				12	0.886
			7	2	1.874
				7	1.445
				12	1.168
			13	2	2.426
				7	1.871
				12	1.527
3	0	200	1	2	0.178
				7	0.113
				12	0.076
			7	2	0.235
				7	0.148
				12	0.100

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	13	2	0.304
				7	0.209
				12	0.150
		800	1	2	0.758
				7	0.574
				12	0.441
			7	2	1.020
				7	0.777
				12	0.613
			13	2	1.316
				7	0.995
				12	0.766
		1400	1	2	1.273
				7	1.001
				12	0.798
			7	2	1.738
				7	1.344
				12	1.077
			13	2	2.233
				7	1.693
				12	1.384
	2	200	1	2	0.169
				7	0.105
				12	0.074
			7	2	0.225
				7	0.153
				12	0.102
			13	2	0.308
				7	0.206
				12	0.144
		800	1	2	0.770
				7	0.566
				12	0.447
			7	2	1.040
				7	0.786
				12	0.605
			13	2	1.298
				7	1.012
				12	0.792
		1400	1	2	1.311
				7	0.987
				12	0.815

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	2	1400	7	2	1.748
				7	1.355
				12	1.076
			13	2	2.181
				7	1.702
				12	1.364
	3	200	1	2	0.187
				7	0.123
				12	0.087
			7	2	0.263
				7	0.167
				12	0.118
			13	2	0.340
				7	0.215
				12	0.173
		800	1	2	0.846
				7	0.639
				12	0.510
			7	2	1.139
				7	0.863
				12	0.688
			13	2	1.465
				7	1.120
				12	0.857
		1400	1	2	1.452
				7	1.145
				12	0.901
			7	2	1.943
				7	1.516
				12	1.237
			13	2	2.486
				7	1.921
				12	1.565

Appendix D. 3:1 Rural Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.090
				7	0.047
				12	0.034
			7	2	0.105
				7	0.075
				12	0.053
			13	2	0.140
				7	0.099
				12	0.071
		800	1	2	0.256
				7	0.184
				12	0.128
			7	2	0.353
				7	0.251
				12	0.182
			13	2	0.456
				7	0.328
				12	0.226
		1400	1	2	0.444
				7	0.317
				12	0.227
			7	2	0.609
				7	0.444
				12	0.309
			13	2	0.771
				7	0.568
				12	0.404
	3	200	1	2	0.075
				7	0.054
				12	0.036
			7	2	0.122
				7	0.084
				12	0.059
			13	2	0.158
				7	0.111
				12	0.076
		800	1	2	0.429
				7	0.306
				12	0.218
			7	2	1.026
				7	0.743
				12	0.519
			13	2	1.158
				7	0.832
				12	0.589
		1400	1	2	0.735
				7	0.549
				12	0.381

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	7	2	1.754
				7	1.262
				12	0.905
			13	2	1.967
				7	1.431
				12	0.996
	6	200	1	2	0.100
				7	0.069
				12	0.049
			7	2	0.158
				7	0.111
				12	0.077
			13	2	0.212
				7	0.146
				12	0.102
		800	1	2	0.576
				7	0.416
				12	0.290
			7	2	1.378
				7	0.985
				12	0.694
			13	2	1.523
				7	1.112
				12	0.775
		1400	1	2	1.004
				7	0.723
				12	0.512
			7	2	2.338
				7	1.697
				12	1.204
			13	2	2.626
				7	1.863
				12	1.343
3	0	200	1	2	0.059
				7	0.035
				12	0.022
			7	2	0.078
				7	0.047
				12	0.029
			13	2	0.095
				7	0.057
				12	0.040
		800	1	2	0.228
				7	0.159
				12	0.110
			7	2	0.317
				7	0.220
				12	0.154

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	800	13	2	0.390
				7	0.281
				12	0.193
		1400	1	2	0.390
				7	0.277
				12	0.194
			7	2	0.528
				7	0.371
				12	0.264
			13	2	0.664
				7	0.478
				12	0.336
	3	200	1	2	0.066
				7	0.039
				12	0.024
			7	2	0.088
				7	0.050
				12	0.034
			13	2	0.112
				7	0.066
				12	0.043
		800	1	2	0.258
				7	0.188
				12	0.126
			7	2	0.347
				7	0.252
				12	0.167
			13	2	0.432
				7	0.321
				12	0.219
		1400	1	2	0.439
				7	0.310
				12	0.222
			7	2	0.591
				7	0.421
				12	0.297
			13	2	0.755
				7	0.534
				12	0.376
	6	200	1	2	0.085
				7	0.050
				12	0.031
			7	2	0.120
				7	0.071
				12	0.045
			13	2	0.144
				7	0.086
				12	0.055

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	800	1	2	0.343
				7	0.244
				12	0.166
			7	2	0.471
				7	0.322
				12	0.227
			13	2	0.586
				7	0.415
				12	0.289
		1400	1	2	0.576
				7	0.420
				12	0.291
			7	2	0.783
				7	0.557
				12	0.393
			13	2	0.990
				7	0.709
				12	0.502
6	0	200	1	2	0.166
				7	0.107
				12	0.067
			7	2	0.221
				7	0.157
				12	0.093
			13	2	0.294
				7	0.198
				12	0.125
		800	1	2	0.669
				7	0.484
				12	0.339
			7	2	0.926
				7	0.655
				12	0.454
			13	2	1.164
				7	0.823
				12	0.580
		1400	1	2	1.104
				7	0.799
				12	0.567
			7	2	1.493
				7	1.067
				12	0.754
			13	2	1.878
				7	1.384
				12	0.956
	3	200	1	2	0.192
				7	0.126
				12	0.080

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3		7	2	0.259
				7	0.175
				12	0.101
			13	2	0.319
				7	0.227
				12	0.138
		800	1	2	0.769
				7	0.544
				12	0.372
			7	2	1.076
				7	0.724
				12	0.507
			13	2	1.310
				7	0.929
				12	0.649
		1400	1	2	1.242
				7	0.916
				12	0.628
			7	2	1.682
				7	1.204
				12	0.853
			13	2	2.121
				7	1.524
				12	1.067
	6	200	1	2	0.254
				7	0.162
				12	0.105
			7	2	0.341
				7	0.225
				12	0.138
			13	2	0.430
				7	0.286
				12	0.176
		800	1	2	1.026
				7	0.736
				12	0.499
			7	2	1.356
				7	0.978
				12	0.680
			13	2	1.732
				7	1.244
				12	0.853
		1400	1	2	1.684
				7	1.194
				12	0.843
			7	2	2.208
				7	1.593
				12	1.129
			13	2	2.820
				7	2.047
				12	1.410

Appendix E. 3:1 Rural Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.135
				7	0.104
				12	0.107
			7	2	0.233
				7	0.181
				12	0.178
			13	2	0.327
				7	0.256
				12	0.262
		800	1	2	0.521
				7	0.416
				12	0.417
			7	2	0.760
				7	0.594
				12	0.606
			13	2	1.011
				7	0.782
				12	0.795
		1400	1	2	0.911
				7	0.728
				12	0.740
			7	2	1.271
				7	1.017
				12	1.017
			13	2	1.646
				7	1.336
				12	1.318
	3	200	1	2	0.152
				7	0.116
				12	0.116
			7	2	0.248
				7	0.210
				12	0.198
			13	2	0.356
				7	0.294
				12	0.290
		800	1	2	0.630
				7	0.471
				12	0.468
			7	2	0.854
				7	0.673
				12	0.683
			13	2	1.104
				7	0.922
				12	0.895
		1400	1	2	1.026
				7	0.818
				12	0.836

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	7	2	1.448
				7	1.160
				12	1.176
			13	2	1.866
				7	1.489
				12	1.514
	6	200	1	2	0.207
				7	0.157
				12	0.152
			7	2	0.347
				7	0.270
				12	0.260
			13	2	0.511
				7	0.404
				12	0.377
		800	1	2	0.784
				7	0.646
				12	0.630
			7	2	1.133
				7	0.916
				12	0.908
			13	2	1.469
				7	1.194
				12	1.192
		1400	1	2	1.353
				7	1.098
				12	1.095
			7	2	1.910
				7	1.533
				12	1.551
			13	2	2.472
				7	1.989
				12	2.009
3	0	200	1	2	0.116
				7	0.070
				12	0.068
			7	2	0.147
				7	0.098
				12	0.104
			13	2	0.186
				7	0.121
				12	0.126
		800	1	2	0.462
				7	0.363
				12	0.359
			7	2	0.739
				7	0.614
				12	0.592

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	800	13	2	1.011
				7	0.797
				12	0.815
		1400	1	2	0.796
				7	0.622
				12	0.625
			7	2	1.053
				7	0.843
				12	0.834
			13	2	1.346
				7	1.048
				12	1.056
	3	200	1	2	0.132
				7	0.077
				12	0.077
			7	2	0.170
				7	0.102
				12	0.113
			13	2	0.227
				7	0.142
				12	0.140
		800	1	2	0.529
				7	0.417
				12	0.411
			7	2	0.716
				7	0.553
				12	0.544
			13	2	0.891
				7	0.679
				12	0.704
		1400	1	2	0.907
				7	0.703
				12	0.692
			7	2	1.205
				7	0.946
				12	0.947
			13	2	1.502
				7	1.176
				12	1.189
	6	200	1	2	0.164
				7	0.102
				12	0.102
			7	2	0.233
				7	0.146
				12	0.147
			13	2	0.296
				7	0.195
				12	0.188

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	800	1	2	0.677
				7	0.540
				12	0.551
			7	2	0.939
				7	0.732
				12	0.723
			13	2	1.215
				7	0.920
				12	0.957
		1400	1	2	1.198
				7	0.936
				12	0.928
			7	2	1.582
				7	1.265
				12	1.261
			13	2	2.045
				7	1.594
				12	1.605
6	0	200	1	2	0.325
				7	0.233
				12	0.220
			7	2	0.435
				7	0.292
				12	0.316
			13	2	0.592
				7	0.374
				12	0.388
		800	1	2	1.356
				7	1.070
				12	1.065
			7	2	1.828
				7	1.454
				12	1.394
			13	2	2.344
				7	1.840
				12	1.835
		1400	1	2	2.214
				7	1.755
				12	1.758
			7	2	2.994
				7	2.378
				12	2.380
			13	2	3.844
				7	3.037
				12	2.974
	3	200	1	2	0.369
				7	0.262
				12	0.258

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3		7	2	0.499
				7	0.349
				12	0.348
			13	2	0.615
				7	0.462
				12	0.439
		800	1	2	1.575
				7	1.239
				12	1.206
			7	2	2.115
				7	1.587
				12	1.560
			13	2	2.627
				7	2.031
				12	2.028
		1400	1	2	2.512
				7	1.927
				12	1.975
			7	2	3.347
				7	2.657
				12	2.643
			13	2	4.222
				7	3.398
				12	3.364
	6	200	1	2	0.477
				7	0.347
				12	0.340
			7	2	0.691
				7	0.471
				12	0.464
			13	2	0.882
				7	0.585
				12	0.613
		800	1	2	2.055
				7	1.596
				12	1.612
			7	2	2.806
				7	2.185
				12	2.157
			13	2	3.538
				7	2.688
				12	2.709
		1400	1	2	3.352
				7	2.647
				12	2.673
			7	2	4.482
				7	3.546
				12	3.477
			13	2	5.610
				7	4.522
				12	4.533

Appendix F. 3:1 Rural Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.667
				7	0.458
				12	0.318
			7	2	0.985
				7	0.677
				12	0.504
			13	2	1.332
				7	0.899
				12	0.636
		800	1	2	2.393
				7	1.718
				12	1.217
			7	2	3.344
				7	2.441
				12	1.690
			13	2	4.274
				7	3.143
				12	2.190
		1400	1	2	4.055
				7	3.028
				12	2.126
			7	2	5.640
				7	4.177
				12	2.947
			13	2	7.094
				7	5.200
				12	3.699
	4	200	1	2	0.829
				7	0.544
				12	0.397
			7	2	1.226
				7	0.872
				12	0.627
			13	2	1.598
				7	1.131
				12	0.780
		800	1	2	3.009
				7	2.213
				12	1.501
			7	2	4.199
				7	3.012
				12	2.148

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	4	800	13	2	5.385
				7	3.763
				12	2.719
		1400	1	2	5.088
				7	3.719
				12	2.661
			7	2	7.133
				7	5.167
				12	3.649
			13	2	9.008
				7	6.556
				12	4.667
	8	200	1	2	1.001
				7	0.670
				12	0.478
			7	2	1.506
				7	1.019
				12	0.724
			13	2	1.894
				7	1.343
				12	0.964
		800	1	2	3.696
				7	2.608
				12	1.868
			7	2	4.944
				7	3.617
				12	2.536
			13	2	6.431
				7	4.722
				12	3.360
		1400	1	2	6.147
				7	4.477
				12	3.207
			7	2	8.503
				7	6.174
				12	4.450
			13	2	10.784
				7	7.886
				12	5.660
4	0	200	1	2	1.309
				7	0.894
				12	0.571

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	200	7	2	1.728
				7	1.224
				12	0.819
			13	2	2.222
				7	1.580
				12	1.010
		800	1	2	4.873
				7	3.543
				12	2.480
			7	2	6.819
				7	4.939
				12	3.481
			13	2	8.756
				7	6.141
				12	4.350
		1400	1	2	8.380
				7	6.042
				12	4.308
			7	2	11.367
				7	8.286
				12	5.923
			13	2	14.557
				7	10.575
				12	7.436
	4	200	1	2	1.503
				7	1.098
				12	0.714
			7	2	2.289
				7	1.616
				12	1.044
			13	2	2.809
				7	1.989
				12	1.240
		800	1	2	6.005
				7	4.403
				12	3.169
			7	2	8.338
				7	6.172
				12	4.287
			13	2	10.896
				7	7.857
				12	5.466

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	4	1400	1	2	10.515
				7	7.690
				12	5.456
			7	2	14.375
				7	10.490
				12	7.376
			13	2	18.104
				7	13.130
				12	9.262
	8	200	1	2	1.539
				7	1.060
				12	0.714
			7	2	2.248
				7	1.533
				12	1.032
			13	2	2.749
				7	1.973
				12	1.343
		800	1	2	6.115
				7	4.515
				12	3.125
			7	2	8.492
				7	6.116
				12	4.287
			13	2	10.693
				7	7.776
				12	5.440
		1400	1	2	10.658
				7	7.719
				12	5.479
			7	2	14.355
				7	10.373
				12	7.448
			13	2	17.801
				7	13.019
				12	9.207
8	0	200	1	2	1.849
				7	1.186
				12	0.790
			7	2	2.464
				7	1.712
				12	1.061

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	0	200	13	2	3.111
				7	2.018
				12	1.349
		800	1	2	6.422
				7	4.864
				12	3.338
			7	2	8.992
				7	6.562
				12	4.551
			13	2	11.341
				7	8.137
				12	5.698
		1400	1	2	10.531
				7	7.574
				12	5.402
			7	2	14.299
				7	10.355
				12	7.163
			13	2	18.189
				7	13.133
				12	9.287
	4	200	1	2	1.883
				7	1.170
				12	0.751
			7	2	2.500
				7	1.647
				12	1.037
			13	2	3.257
				7	2.176
				12	1.327
		800	1	2	6.618
				7	4.670
				12	3.267
			7	2	8.992
				7	6.503
				12	4.515
			13	2	11.392
				7	8.125
				12	5.652
		1400	1	2	10.477
				7	7.467
				12	5.334

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	4	1400	7	2	14.296
				7	10.413
				12	7.341
			13	2	18.108
				7	12.951
				12	9.039
	8	200	1	2	2.691
				7	1.816
				12	1.077
			7	2	3.626
				7	2.493
				12	1.514
			13	2	4.783
				7	3.155
				12	2.066
		800	1	2	9.867
				7	7.099
				12	4.983
			7	2	13.130
				7	9.515
				12	6.564
			13	2	16.886
				7	12.142
				12	8.694
		1400	1	2	15.914
				7	11.501
				12	8.005
			7	2	21.281
				7	15.505
				12	10.648
			13	2	26.844
				7	19.444
				12	13.823

Appendix G. 3:1 Urban Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.059
				7	0.042
				12	0.029
			7	2	0.094
				7	0.066
				12	0.047
			13	2	0.118
				7	0.082
				12	0.058
		800	1	2	0.227
				7	0.162
				12	0.115
			7	2	0.321
				7	0.230
				12	0.164
			13	2	0.399
				7	0.283
				12	0.200
		1400	1	2	0.392
				7	0.286
				12	0.201
			7	2	0.547
				7	0.394
				12	0.284
			13	2	0.667
				7	0.484
				12	0.346
	3	200	1	2	0.067
				7	0.045
				12	0.032
			7	2	0.106
				7	0.075
				12	0.052
			13	2	0.134
				7	0.094
				12	0.064
		800	1	2	0.255
				7	0.183
				12	0.129
			7	2	0.362
				7	0.260
				12	0.183
			13	2	0.444
				7	0.323
				12	0.225
		1400	1	2	0.438
				7	0.321
				12	0.227

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	7	2	0.621
				7	0.450
				12	0.321
			13	2	0.748
				7	0.548
				12	0.385
	6	200	1	2	0.092
				7	0.062
				12	0.042
			7	2	0.143
				7	0.095
				12	0.069
			13	2	0.176
				7	0.122
				12	0.085
		800	1	2	0.338
				7	0.243
				12	0.172
			7	2	0.481
				7	0.349
				12	0.243
			13	2	0.587
				7	0.426
				12	0.300
		1400	1	2	0.587
				7	0.426
				12	0.306
			7	2	0.816
				7	0.600
				12	0.424
			13	2	1.008
				7	0.723
				12	0.520
4	0	200	1	2	0.105
				7	0.069
				12	0.046
			7	2	0.144
				7	0.097
				12	0.061
			13	2	0.176
				7	0.115
				12	0.075
		800	1	2	0.422
				7	0.304
				12	0.213
			7	2	0.583
				7	0.414
				12	0.289

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	800	13	2	0.712
				7	0.510
				12	0.351
		1400	1	2	0.745
				7	0.529
				12	0.378
			7	2	1.001
				7	0.726
				12	0.505
			13	2	1.212
				7	0.881
				12	0.615
	3	200	1	2	0.116
				7	0.077
				12	0.049
			7	2	0.161
				7	0.110
				12	0.068
			13	2	0.187
				7	0.132
				12	0.085
		800	1	2	0.483
				7	0.342
				12	0.244
			7	2	0.660
				7	0.466
				12	0.324
			13	2	0.798
				7	0.560
				12	0.400
		1400	1	2	0.826
				7	0.591
				12	0.416
			7	2	1.139
				7	0.813
				12	0.575
			13	2	1.384
				7	0.980
				12	0.698
	6	200	1	2	0.154
				7	0.103
				12	0.067
			7	2	0.216
				7	0.138
				12	0.089
			13	2	0.261
				7	0.177
				12	0.111

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	800	1	2	0.640
				7	0.462
				12	0.321
			7	2	0.875
				7	0.629
				12	0.440
			13	2	1.063
				7	0.757
				12	0.527
		1400	1	2	1.103
				7	0.790
				12	0.558
			7	2	1.500
				7	1.088
				12	0.760
			13	2	1.849
				7	1.315
				12	0.931
8	0	200	1	2	0.147
				7	0.095
				12	0.058
			7	2	0.210
				7	0.133
				12	0.082
			13	2	0.254
				7	0.160
				12	0.101
		800	1	2	0.563
				7	0.403
				12	0.279
			7	2	0.771
				7	0.550
				12	0.382
			13	2	0.939
				7	0.665
				12	0.475
		1400	1	2	0.892
				7	0.643
				12	0.453
			7	2	1.231
				7	0.886
				12	0.618
			13	2	1.494
				7	1.072
				12	0.749
	3	200	1	2	0.164
				7	0.108
				12	0.066

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3		7	2	0.230
				7	0.150
				12	0.092
			13	2	0.281
				7	0.181
				12	0.112
		800	1	2	0.638
				7	0.450
				12	0.318
			7	2	0.878
				7	0.617
				12	0.434
			13	2	1.050
				7	0.754
				12	0.538
		1400	1	2	1.021
				7	0.731
				12	0.515
			7	2	1.389
				7	0.991
				12	0.694
			13	2	1.681
				7	1.210
				12	0.846
	6	200	1	2	0.227
				7	0.141
				12	0.089
			7	2	0.307
				7	0.195
				12	0.120
			13	2	0.390
				7	0.239
				12	0.151
		800	1	2	0.852
				7	0.609
				12	0.421
			7	2	1.154
				7	0.835
				12	0.577
			13	2	1.408
				7	1.003
				12	0.691
		1400	1	2	1.354
				7	0.960
				12	0.685
			7	2	1.863
				7	1.321
				12	0.919
			13	2	2.220
				7	1.621
				12	1.130

Appendix H. 3:1 Urban Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.119
				7	0.089
				12	0.072
			7	2	0.197
				7	0.153
				12	0.128
			13	2	0.265
				7	0.203
				12	0.173
		800	1	2	0.467
				7	0.364
				12	0.295
			7	2	0.657
				7	0.526
				12	0.431
			13	2	0.840
				7	0.673
				12	0.429
		1400	1	2	0.804
				7	0.636
				12	0.522
			7	2	1.140
				7	0.906
				12	0.726
			13	2	1.401
				7	1.121
				12	0.736
	3	200	1	2	0.129
				7	0.102
				12	0.078
			7	2	0.220
				7	0.173
				12	0.142
			13	2	0.308
				7	0.236
				12	0.140
		800	1	2	0.523
				7	0.409
				12	0.330
			7	2	0.745
				7	0.594
				12	0.485
			13	2	0.943
				7	0.756
				12	0.483
		1400	1	2	0.899
				7	0.719
				12	0.586

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	7	2	1.275
				7	1.022
				12	0.838
			13	2	1.582
				7	1.291
				12	0.840
	6	200	1	2	0.176
				7	0.134
				12	0.107
			7	2	0.300
				7	0.227
				12	0.186
			13	2	0.403
				7	0.325
				12	0.189
		800	1	2	0.699
				7	0.552
				12	0.438
			7	2	0.997
				7	0.794
				12	0.643
			13	2	1.254
				7	1.015
				12	0.642
		1400	1	2	1.214
				7	0.953
				12	0.779
			7	2	1.691
				7	1.369
				12	1.112
			13	2	2.125
				7	1.691
				12	1.114
4	0	200	1	2	0.199
				7	0.136
				12	0.104
			7	2	0.264
				7	0.195
				12	0.137
			13	2	0.339
				7	0.243
				12	0.170
		800	1	2	0.847
				7	0.662
				12	0.535
			7	2	1.156
				7	0.915
				12	0.719

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	800	13	2	1.382
				7	1.103
				12	0.725
		1400	1	2	1.492
				7	1.167
				12	0.926
			7	2	2.008
				7	1.565
				12	1.272
			13	2	2.479
				7	1.912
				12	1.262
	3	200	1	2	0.211
				7	0.162
				12	0.117
			7	2	0.301
				7	0.214
				12	0.159
			13	2	0.368
				7	0.269
				12	0.161
		800	1	2	0.948
				7	0.733
				12	0.586
			7	2	1.314
				7	1.040
				12	0.816
			13	2	1.590
				7	1.239
				12	0.807
		1400	1	2	1.661
				7	1.297
				12	1.059
			7	2	2.252
				7	1.791
				12	1.447
			13	2	2.741
				7	2.154
				12	1.425
	6	200	1	2	0.293
				7	0.215
				12	0.149
			7	2	0.405
				7	0.290
				12	0.207
			13	2	0.523
				7	0.360
				12	0.205

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	800	1	2	1.285
				7	0.995
				12	0.799
			7	2	1.736
				7	1.348
				12	1.074
			13	2	2.076
				7	1.658
				12	1.091
		1400	1	2	2.208
				7	1.743
				12	1.402
			7	2	3.019
				7	2.389
				12	1.921
			13	2	3.641
				7	2.881
				12	1.900
8	0	200	1	2	0.293
				7	0.196
				12	0.134
			7	2	0.399
				7	0.262
				12	0.183
			13	2	0.476
				7	0.324
				12	0.221
		800	1	2	1.113
				7	0.871
				12	0.695
			7	2	1.539
				7	1.183
				12	0.941
			13	2	1.825
				7	1.427
				12	0.936
		1400	1	2	1.788
				7	1.377
				12	1.130
			7	2	2.403
				7	1.886
				12	1.545
			13	2	2.957
				7	2.279
				12	1.529
	3	200	1	2	0.319
				7	0.226
				12	0.151

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3		7	2	0.427
				7	0.304
				12	0.205
			13	2	0.541
				7	0.369
				12	0.201
		800	1	2	1.271
				7	0.963
				12	0.777
			7	2	1.702
				7	1.320
				12	1.062
			13	2	2.044
				7	1.606
				12	1.052
		1400	1	2	1.990
				7	1.540
				12	1.250
			7	2	2.716
				7	2.114
				12	1.707
			13	2	3.286
				7	2.551
				12	1.704
	6	200	1	2	0.428
				7	0.293
				12	0.202
			7	2	0.577
				7	0.406
				12	0.278
			13	2	0.707
				7	0.497
				12	0.276
		800	1	2	1.641
				7	1.306
				12	1.029
			7	2	2.267
				7	1.789
				12	1.407
			13	2	2.747
				7	2.158
				12	1.404
		1400	1	2	2.686
				7	2.105
				12	1.667
			7	2	3.656
				7	2.851
				12	2.262
			13	2	4.396
				7	3.439
				12	2.276

Appendix I. 3:1 Urban Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.226
				7	0.159
				12	0.111
			7	2	0.348
				7	0.235
				12	0.175
			13	2	0.439
				7	0.310
				12	0.216
		800	1	2	0.800
				7	0.587
				12	0.417
			7	2	1.096
				7	0.811
				12	0.573
			13	2	1.377
				7	1.003
				12	0.706
		1400	1	2	1.384
				7	1.008
				12	0.718
			7	2	1.875
				7	1.372
				12	0.975
			13	2	2.287
				7	1.670
				12	1.196
	6	200	1	2	0.337
				7	0.238
				12	0.165
			7	2	0.531
				7	0.365
				12	0.259
			13	2	0.666
				7	0.455
				12	0.330
		800	1	2	1.219
				7	0.861
				12	0.616
			7	2	1.662
				7	1.222
				12	0.855

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	6	800	13	2	2.042
				7	1.496
				12	1.075
		1400	1	2	2.060
				7	1.504
				12	1.080
			7	2	2.812
				7	2.064
				12	1.463
			13	2	3.446
				7	2.500
				12	1.789
	12	200	1	2	0.338
				7	0.240
				12	0.166
			7	2	0.518
				7	0.361
				12	0.259
			13	2	0.668
				7	0.466
				12	0.327
		800	1	2	1.194
				7	0.863
				12	0.606
			7	2	1.663
				7	1.210
				12	0.872
			13	2	2.047
				7	1.473
				12	1.065
		1400	1	2	2.063
				7	1.513
				12	1.074
			7	2	2.805
				7	2.062
				12	1.454
			13	2	3.471
				7	2.492
				12	1.794
3	0	200	1	2	0.203
				7	0.129
				12	0.084

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	7	2	0.280
				7	0.177
				12	0.120
			13	2	0.351
				7	0.211
				12	0.150
		800	1	2	0.772
				7	0.548
				12	0.392
			7	2	1.048
				7	0.743
				12	0.511
			13	2	1.277
				7	0.918
				12	0.643
		1400	1	2	1.303
				7	0.954
				12	0.665
			7	2	1.725
				7	1.248
				12	0.894
			13	2	2.117
				7	1.525
				12	1.089
	6	200	1	2	0.311
				7	0.194
				12	0.126
			7	2	0.423
				7	0.260
				12	0.177
			13	2	0.519
				7	0.329
				12	0.220
		800	1	2	1.164
				7	0.817
				12	0.580
			7	2	1.536
				7	1.113
				12	0.764
			13	2	1.902
				7	1.360
				12	0.947

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	1400	1	2	1.952
				7	1.403
				12	0.992
			7	2	2.563
				7	1.867
				12	1.325
			13	2	3.155
				7	2.278
				12	1.605
	12	200	1	2	0.296
				7	0.193
				12	0.127
			7	2	0.420
				7	0.267
				12	0.180
			13	2	0.493
				7	0.328
				12	0.221
		800	1	2	1.155
				7	0.836
				12	0.577
			7	2	1.530
				7	1.113
				12	0.788
			13	2	1.900
				7	1.368
				12	0.946
		1400	1	2	1.926
				7	1.398
				12	0.988
			7	2	2.598
				7	1.883
				12	1.329
			13	2	3.140
				7	2.317
				12	1.620
6	0	200	1	2	0.606
				7	0.411
				12	0.273
			7	2	0.831
				7	0.573
				12	0.371

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	0	200	13	2	1.022
				7	0.677
				12	0.461
		800	1	2	2.270
				7	1.651
				12	1.154
			7	2	3.088
				7	2.232
				12	1.587
			13	2	3.785
				7	2.708
				12	1.888
		1400	1	2	3.743
				7	2.717
				12	1.935
			7	2	5.047
				7	3.667
				12	2.566
			13	2	6.185
				7	4.508
				12	3.148
	6	200	1	2	0.898
				7	0.610
				12	0.405
			7	2	1.238
				7	0.837
				12	0.553
			13	2	1.547
				7	1.053
				12	0.659
		800	1	2	3.412
				7	2.506
				12	1.728
			7	2	4.593
				7	3.338
				12	2.344
			13	2	5.733
				7	4.102
				12	2.886
		1400	1	2	5.628
				7	4.088
				12	2.903

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	6	1400	7	2	7.582
				7	5.461
				12	3.909
			13	2	9.220
				7	6.733
				12	4.728
	12	200	1	2	0.883
				7	0.618
				12	0.409
			7	2	1.177
				7	0.871
				12	0.562
			13	2	1.531
				7	1.032
				12	0.697
		800	1	2	3.446
				7	2.511
				12	1.747
			7	2	4.625
				7	3.335
				12	2.389
			13	2	5.633
				7	4.169
				12	2.881
		1400	1	2	5.730
				7	4.099
				12	2.932
			7	2	7.569
				7	5.486
				12	3.907
			13	2	9.367
				7	6.740
				12	4.695

Appendix J. 4:1 Freeway Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.068
				7	0.053
				12	0.040
			7	2	0.358
				7	0.281
				12	0.236
			13	2	0.405
				7	0.302
				12	0.260
		800	1	2	0.265
				7	0.201
				12	0.163
			7	2	1.108
				7	0.902
				12	0.716
			13	2	1.156
				7	0.924
				12	0.751
		1400	1	2	0.450
				7	0.363
				12	0.293
			7	2	1.914
				7	1.486
				12	1.231
			13	2	1.948
				7	1.557
				12	1.243
	2	200	1	2	0.071
				7	0.052
				12	0.042
			7	2	0.365
				7	0.281
				12	0.237
			13	2	0.408
				7	0.310
				12	0.267
		800	1	2	0.262
				7	0.202
				12	0.168
			7	2	1.118
				7	0.879
				12	0.747

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	2	800	13	2	1.147
				7	0.913
				12	0.750
		1400	1	2	0.453
				7	0.357
				12	0.288
			7	2	1.851
				7	1.503
				12	1.237
			13	2	1.948
				7	1.535
				12	1.256
	3	200	1	2	0.078
				7	0.058
				12	0.046
			7	2	0.415
				7	0.310
				12	0.263
			13	2	0.449
				7	0.350
				12	0.291
		800	1	2	0.293
				7	0.227
				12	0.186
			7	2	1.277
				7	0.993
				12	0.826
			13	2	1.322
				7	1.051
				12	0.859
		1400	1	2	0.509
				7	0.409
				12	0.333
			7	2	2.128
				7	1.700
				12	1.401
			13	2	2.181
				7	1.730
				12	1.426
2	0	200	1	2	0.049
				7	0.029
				12	0.022

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
2	0	200	7	2	0.187
				7	0.130
				12	0.097
			13	2	0.210
				7	0.154
				12	0.109
		800	1	2	0.217
				7	0.165
				12	0.129
			7	2	0.842
				7	0.683
				12	0.523
			13	2	0.904
				7	0.668
				12	0.541
		1400	1	2	0.376
				7	0.291
				12	0.233
			7	2	1.521
				7	1.156
				12	0.941
			13	2	1.537
				7	1.170
				12	0.950
	2	200	1	2	0.047
				7	0.032
				12	0.020
			7	2	0.200
				7	0.132
				12	0.099
			13	2	0.206
				7	0.149
				12	0.112
		800	1	2	0.212
				7	0.166
				12	0.129
			7	2	0.876
				7	0.656
				12	0.532
			13	2	0.875
				7	0.663
				12	0.544

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
2	2	1400	1	2	0.374
				7	0.295
				12	0.235
			7	2	1.545
				7	1.157
				12	0.947
			13	2	1.537
				7	1.183
				12	0.957
	3	200	1	2	0.048
				7	0.033
				12	0.021
			7	2	0.191
				7	0.129
				12	0.091
			13	2	0.207
				7	0.153
				12	0.110
		800	1	2	0.221
				7	0.163
				12	0.129
			7	2	0.858
				7	0.656
				12	0.525
			13	2	0.905
				7	0.682
				12	0.544
		1400	1	2	0.375
				7	0.295
				12	0.232
			7	2	1.491
				7	1.160
				12	0.935
			13	2	1.516
				7	1.166
				12	0.954
3	0	200	1	2	0.053
				7	0.034
				12	0.024
			7	2	0.215
				7	0.131
				12	0.098

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	13	2	0.229
				7	0.145
				12	0.105
		800	1	2	0.230
				7	0.174
				12	0.135
			7	2	0.921
				7	0.684
				12	0.561
			13	2	0.922
				7	0.715
				12	0.558
		1400	1	2	0.388
				7	0.301
				12	0.242
			7	2	1.560
				7	1.492
				12	0.967
			13	2	1.578
				7	1.203
				12	0.969
	2	200	1	2	0.053
				7	0.032
				12	0.023
			7	2	0.211
				7	0.133
				12	0.098
			13	2	0.228
				7	0.148
				12	0.102
		800	1	2	0.226
				7	0.174
				12	0.137
			7	2	0.914
				7	0.688
				12	0.539
			13	2	0.914
				7	0.700
				12	0.551
		1400	1	2	0.389
				7	0.299
				12	0.238

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	2	1400	7	2	1.552
				7	1.199
				12	0.968
			13	2	1.556
				7	1.218
				12	0.967
	3	200	1	2	0.059
				7	0.036
				12	0.027
			7	2	0.233
				7	0.150
				12	0.107
			13	2	0.258
				7	0.164
				12	0.119
		800	1	2	0.259
				7	0.196
				12	0.157
			7	2	1.020
				7	0.770
				12	0.613
			13	2	1.028
				7	0.804
				12	0.616
		1400	1	2	0.436
				7	0.339
				12	0.271
			7	2	1.748
				7	1.358
				12	1.071
			13	2	1.737
				7	1.356
				12	1.109

Appendix K. 4:1 Rural Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.013
				7	0.009
				12	0.007
			7	2	0.052
				7	0.036
				12	0.025
			13	2	0.054
				7	0.037
				12	0.026
		800	1	2	0.050
				7	0.035
				12	0.025
			7	2	0.173
				7	0.125
				12	0.088
			13	2	0.173
				7	0.123
				12	0.087
		1400	1	2	0.085
				7	0.062
				12	0.044
			7	2	0.291
				7	0.215
				12	0.151
			13	2	0.293
				7	0.212
				12	0.151
	3	200	1	2	0.016
				7	0.010
				12	0.007
			7	2	0.060
				7	0.040
				12	0.029
			13	2	0.058
				7	0.041
				12	0.029
		800	1	2	0.055
				7	0.040
				12	0.028
			7	2	0.196
				7	0.140
				12	0.099

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	800	13	2	0.196
				7	0.139
				12	0.098
		1400	1	2	0.096
				7	0.070
				12	0.049
			7	2	0.331
				7	0.234
				12	0.165
			13	2	0.332
				7	0.240
				12	0.170
	6	200	1	2	0.021
				7	0.014
				12	0.010
			7	2	0.076
				7	0.055
				12	0.039
			13	2	0.078
				7	0.054
				12	0.038
		800	1	2	0.074
				7	0.054
				12	0.038
			7	2	0.256
				7	0.185
				12	0.134
			13	2	0.255
				7	0.184
				12	0.132
		1400	1	2	0.128
				7	0.094
				12	0.067
			7	2	0.438
				7	0.321
				12	0.226
			13	2	0.441
				7	0.319
				12	0.228
3	0	200	1	2	0.011
				7	0.007
				12	0.004

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	7	2	0.037
				7	0.022
				12	0.013
			13	2	0.037
				7	0.023
				12	0.014
		800	1	2	0.045
				7	0.031
				12	0.022
			7	2	0.149
				7	0.106
				12	0.073
			13	2	0.149
				7	0.106
				12	0.073
		1400	1	2	0.075
				7	0.054
				12	0.038
			7	2	0.249
				7	0.180
				12	0.124
			13	2	0.247
				7	0.177
				12	0.126
	3	200	1	2	0.013
				7	0.007
				12	0.005
			7	2	0.042
				7	0.026
				12	0.016
			13	2	0.042
				7	0.026
				12	0.017
		800	1	2	0.049
				7	0.036
				12	0.025
			7	2	0.165
				7	0.118
				12	0.081
			13	2	0.167
				7	0.117
				12	0.081

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	3	1400	1	2	0.085
				7	0.060
				12	0.042
			7	2	0.282
				7	0.196
				12	0.144
			13	2	0.285
				7	0.200
				12	0.140
	6	200	1	2	0.017
				7	0.010
				12	0.006
			7	2	0.057
				7	0.034
				12	0.022
			13	2	0.057
				7	0.033
				12	0.022
		800	1	2	0.068
				7	0.047
				12	0.032
			7	2	0.223
				7	0.155
				12	0.108
			13	2	0.225
				7	0.157
				12	0.108
		1400	1	2	0.113
				7	0.081
				12	0.057
			7	2	0.369
				7	0.265
				12	0.190
			13	2	0.364
				7	0.269
				12	0.187
6	0	200	1	2	0.033
				7	0.023
				12	0.014
			7	2	0.115
				7	0.071
				12	0.046

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	0	200	13	2	0.107
				7	0.072
				12	0.046
		800	1	2	0.134
				7	0.091
				12	0.065
			7	2	0.436
				7	0.316
				12	0.221
			13	2	0.437
				7	0.312
				12	0.213
		1400	1	2	0.211
				7	0.155
				12	0.108
			7	2	0.721
				7	0.515
				12	0.362
			13	2	0.714
				7	0.517
				12	0.359
	3	200	1	2	0.036
				7	0.024
				12	0.016
			7	2	0.126
				7	0.081
				12	0.051
			13	2	0.120
				7	0.081
				12	0.051
		800	1	2	0.149
				7	0.105
				12	0.074
			7	2	0.489
				7	0.350
				12	0.244
			13	2	0.497
				7	0.350
				12	0.239
		1400	1	2	0.242
				7	0.171
				12	0.120

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3	1400	7	2	0.796
				7	0.570
				12	0.403
			13	2	0.792
				7	0.584
				12	0.399
	6	200	1	2	0.045
				7	0.032
				12	0.019
			7	2	0.161
				7	0.110
				12	0.070
			13	2	0.160
				7	0.107
				12	0.068
		800	1	2	0.198
				7	0.141
				12	0.099
			7	2	0.673
				7	0.462
				12	0.324
			13	2	0.666
				7	0.463
				12	0.323
		1400	1	2	0.322
				7	0.230
				12	0.162
			7	2	1.069
				7	0.767
				12	0.539
			13	2	1.082
				7	0.775
				12	0.544

Appendix L. 4:1 Rural Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.028
				7	0.020
				12	0.017
			7	2	0.118
				7	0.092
				12	0.077
			13	2	0.134
				7	0.106
				12	0.089
		800	1	2	0.103
				7	0.081
				12	0.065
			7	2	0.368
				7	0.292
				12	0.239
			13	2	0.380
				7	0.301
				12	0.251
		1400	1	2	0.181
				7	0.143
				12	0.118
			7	2	0.620
				7	0.509
				12	0.409
			13	2	0.642
				7	0.507
				12	0.410
	3	200	1	2	0.031
				7	0.023
				12	0.018
			7	2	0.132
				7	0.104
				12	0.086
			13	2	0.149
				7	0.116
				12	0.096
		800	1	2	0.116
				7	0.092
				12	0.073
			7	2	0.417
				7	0.327
				12	0.266

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	800	13	2	0.427
				7	0.347
				12	0.281
		1400	1	2	0.197
				7	0.161
				12	0.131
			7	2	0.689
				7	0.571
				12	0.461
			13	2	0.733
				7	0.583
				12	0.469
	6	200	1	2	0.042
				7	0.030
				12	0.025
			7	2	0.176
				7	0.133
				12	0.115
			13	2	0.198
				7	0.160
				12	0.126
		800	1	2	0.152
				7	0.124
				12	0.098
			7	2	0.557
				7	0.436
				12	0.364
			13	2	0.574
				7	0.462
				12	0.361
		1400	1	2	0.270
				7	0.216
				12	0.175
			7	2	0.944
				7	0.742
				12	0.615
			13	2	0.953
				7	0.772
				12	0.621
3	0	200	1	2	0.022
				7	0.014
				12	0.009

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	7	2	0.073
				7	0.044
				12	0.034
			13	2	0.074
				7	0.050
				12	0.038
		800	1	2	0.088
				7	0.069
				12	0.054
			7	2	0.299
				7	0.237
				12	0.185
			13	2	0.308
				7	0.236
				12	0.185
		1400	1	2	0.151
				7	0.120
				12	0.096
			7	2	0.506
				7	0.400
				12	0.324
			13	2	0.507
				7	0.405
				12	0.324
	3	200	1	2	0.024
				7	0.015
				12	0.011
			7	2	0.083
				7	0.049
				12	0.038
			13	2	0.084
				7	0.057
				12	0.041
		800	1	2	0.102
				7	0.078
				12	0.062
			7	2	0.340
				7	0.273
				12	0.209
			13	2	0.349
				7	0.269
				12	0.207

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	3	1400	1	2	0.171
				7	0.137
				12	0.109
			7	2	0.570
				7	0.455
				12	0.359
			13	2	0.581
				7	0.449
				12	0.366
	6	200	1	2	0.032
				7	0.020
				12	0.015
			7	2	0.113
				7	0.070
				12	0.048
			13	2	0.119
				7	0.074
				12	0.056
		800	1	2	0.134
				7	0.106
				12	0.082
			7	2	0.454
				7	0.343
				12	0.274
			13	2	0.452
				7	0.354
				12	0.274
		1400	1	2	0.229
				7	0.181
				12	0.145
			7	2	0.762
				7	0.599
				12	0.485
			13	2	0.768
				7	0.599
				12	0.477
6	0	200	1	2	0.065
				7	0.043
				12	0.032
			7	2	0.221
				7	0.141
				12	0.106

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	0	200	13	2	0.201
				7	0.156
				12	0.104
		800	1	2	0.270
				7	0.208
				12	0.168
			7	2	0.862
				7	0.685
				12	0.553
			13	2	0.892
				7	0.687
				12	0.560
		1400	1	2	0.434
				7	0.344
				12	0.273
			7	2	1.412
				7	1.126
				12	0.913
			13	2	1.434
				7	1.118
				12	0.894
	3	200	1	2	0.070
				7	0.050
				12	0.035
			7	2	0.240
				7	0.176
				12	0.120
			13	2	0.239
				7	0.172
				12	0.121
		800	1	2	0.297
				7	0.228
				12	0.187
			7	2	0.966
				7	0.781
				12	0.628
			13	2	1.005
				7	0.773
				12	0.610
		1400	1	2	0.492
				7	0.382
				12	0.300

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3	1400	7	2	1.614
				7	1.263
				12	1.029
			13	2	1.621
				7	1.271
				12	1.042
	6	200	1	2	0.098
				7	0.068
				12	0.048
			7	2	0.330
				7	0.232
				12	0.163
			13	2	0.297
				7	0.234
				12	0.166
		800	1	2	0.393
				7	0.308
				12	0.246
			7	2	1.344
				7	1.027
				12	0.810
			13	2	1.314
				7	1.008
				12	0.822
		1400	1	2	0.651
				7	0.503
				12	0.414
			7	2	2.150
				7	1.681
				12	1.373
			13	2	2.161
				7	1.682
				12	1.362

Appendix M. 4:1 Rural Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.121
				7	0.085
				12	0.058
			7	2	0.481
				7	0.334
				12	0.239
			13	2	0.480
				7	0.347
				12	0.243
		800	1	2	0.435
				7	0.309
				12	0.224
			7	2	1.565
				7	1.154
				12	0.807
			13	2	1.572
				7	1.138
				12	0.825
		1400	1	2	0.743
				7	0.532
				12	0.386
			7	2	2.720
				7	1.967
				12	1.397
			13	2	2.717
				7	1.972
				12	1.409
	4	200	1	2	0.153
				7	0.104
				12	0.071
			7	2	0.624
				7	0.405
				12	0.291
			13	2	0.604
				7	0.432
				12	0.291
		800	1	2	0.531
				7	0.393
				12	0.275
			7	2	1.988
				7	1.422
				12	1.003

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	4	800	13	2	1.975
				7	1.431
				12	1.029
		1400	1	2	0.934
				7	0.670
				12	0.491
			7	2	3.344
				7	2.467
				12	1.731
			13	2	3.370
				7	2.461
				12	1.754
	8	200	1	2	0.187
				7	0.124
				12	0.086
			7	2	0.744
				7	0.501
				12	0.354
			13	2	0.725
				7	0.496
				12	0.353
		800	1	2	0.645
				7	0.470
				12	0.321
			7	2	2.366
				7	1.738
				12	1.202
			13	2	2.433
				7	1.742
				12	1.223
		1400	1	2	1.114
				7	0.804
				12	0.582
			7	2	4.064
				7	2.945
				12	2.103
			13	2	4.077
				7	2.976
				12	2.123
4	0	200	1	2	0.223
				7	0.160
				12	0.107

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	200	7	2	0.828
				7	0.574
				12	0.380
			13	2	0.855
				7	0.565
				12	0.423
		800	1	2	0.892
				7	0.642
				12	0.453
			7	2	3.219
				7	2.314
				12	1.620
			13	2	3.233
				7	2.305
				12	1.647
		1400	1	2	1.538
				7	1.126
				12	0.775
			7	2	5.494
				7	3.967
				12	2.763
			13	2	5.483
				7	3.918
				12	2.792
	4	200	1	2	0.275
				7	0.208
				12	0.129
			7	2	1.051
				7	0.740
				12	0.472
			13	2	1.067
				7	0.737
				12	0.475
		800	1	2	1.122
				7	0.804
				12	0.569
			7	2	3.968
				7	2.888
				12	2.063
			13	2	3.998
				7	2.923
				12	2.055

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	4	1400	1	2	1.900
				7	1.389
				12	0.986
			7	2	6.816
				7	4.979
				12	3.428
			13	2	6.801
				7	4.923
				12	3.462
	8	200	1	2	0.336
				7	0.232
				12	0.161
			7	2	1.294
				7	0.963
				12	0.590
			13	2	1.213
				7	0.862
				12	0.580
		800	1	2	1.327
				7	0.968
				12	0.681
			7	2	4.720
				7	3.506
				12	2.446
			13	2	4.865
				7	3.479
				12	2.412
		1400	1	2	2.306
				7	1.655
				12	1.158
			7	2	8.224
				7	5.910
				12	4.210
			13	2	8.098
				7	5.851
				12	4.210
8	0	200	1	2	0.316
				7	0.218
				12	0.138
			7	2	1.257
				7	0.819
				12	0.507

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	0	200	13	2	1.194
				7	0.773
				12	0.499
		800	1	2	1.156
				7	0.842
				12	0.600
			7	2	4.238
				7	3.052
				12	2.136
			13	2	4.224
				7	3.037
				12	2.103
		1400	1	2	1.887
				7	1.362
				12	0.966
			7	2	6.717
				7	4.891
				12	3.496
			13	2	6.691
				7	4.885
				12	3.423
	4	200	1	2	0.419
				7	0.282
				12	0.165
			7	2	1.534
				7	1.008
				12	0.629
			13	2	1.479
				7	0.982
				12	0.632
		800	1	2	1.464
				7	1.070
				12	0.760
			7	2	5.246
				7	3.880
				12	2.711
			13	2	5.294
				7	3.833
				12	2.656
		1400	1	2	2.340
				7	1.728
				12	1.204

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	4	1400	7	2	8.235
				7	6.042
				12	4.306
			13	2	8.488
				7	6.212
				12	4.317
	8	200	1	2	0.486
				7	0.319
				12	0.205
			7	2	1.830
				7	1.182
				12	0.754
			13	2	1.739
				7	1.204
				12	0.748
		800	1	2	1.751
				7	1.279
				12	0.901
			7	2	6.205
				7	4.672
				12	3.216
			13	2	6.520
				7	4.568
				12	3.270
		1400	1	2	2.848
				7	2.044
				12	1.459
			7	2	10.248
				7	7.308
				12	5.109
			13	2	10.030
				7	7.284
				12	5.200

Appendix N. 4:1 Urban Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.012
				7	0.008
				12	0.013
			7	2	0.048
				7	0.034
				12	0.047
			13	2	0.048
				7	0.034
				12	0.048
		800	1	2	0.044
				7	0.032
				12	0.046
			7	2	0.160
				7	0.115
				12	0.161
			13	2	0.161
				7	0.116
				12	0.162
		1400	1	2	0.076
				7	0.056
				12	0.079
			7	2	0.275
				7	0.199
				12	0.274
			13	2	0.275
				7	0.200
				12	0.276
	3	200	1	2	0.013
				7	0.009
				12	0.014
			7	2	0.054
				7	0.038
				12	0.054
			13	2	0.054
				7	0.039
				12	0.055
		800	1	2	0.050
				7	0.036
				12	0.051
			7	2	0.183
				7	0.129
				12	0.182
			13	2	0.181
				7	0.130
				12	0.182
		1400	1	2	0.086
				7	0.063
				12	0.087
			7	2	0.310
				7	0.225
				12	0.308

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	0.308
				7	0.225
				12	0.308
	6	200	1	2	0.018
				7	0.012
				12	0.020
			7	2	0.074
				7	0.049
				12	0.072
			13	2	0.073
				7	0.050
				12	0.072
		800	1	2	0.067
				7	0.047
				12	0.068
			7	2	0.242
				7	0.175
				12	0.238
			13	2	0.240
				7	0.172
				12	0.240
		1400	1	2	0.116
				7	0.084
				12	0.116
			7	2	0.414
				7	0.295
				12	0.412
			13	2	0.409
				7	0.299
				12	0.413
4	0	200	1	2	0.020
				7	0.013
				12	0.020
			7	2	0.073
				7	0.048
				12	0.072
			13	2	0.071
				7	0.046
				12	0.071
		800	1	2	0.083
				7	0.060
				12	0.083
			7	2	0.287
				7	0.210
				12	0.292
			13	2	0.292
				7	0.206
				12	0.288
		1400	1	2	0.143
				7	0.103
				12	0.144

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	1400	7	2	0.498
				7	0.360
				12	0.503
			13	2	0.498
				7	0.359
				12	0.503
	3	200	1	2	0.023
				7	0.015
				12	0.023
			7	2	0.080
				7	0.054
				12	0.077
			13	2	0.077
				7	0.053
				12	0.081
		800	1	2	0.094
				7	0.066
				12	0.095
			7	2	0.323
				7	0.233
				12	0.326
			13	2	0.329
				7	0.236
				12	0.326
		1400	1	2	0.161
				7	0.116
				12	0.163
			7	2	0.567
				7	0.404
				12	0.562
			13	2	0.565
				7	0.405
				12	0.560
	6	200	1	2	0.030
				7	0.020
				12	0.030
			7	2	0.106
				7	0.073
				12	0.105
			13	2	0.106
				7	0.070
				12	0.107
		800	1	2	0.126
				7	0.090
				12	0.123
			7	2	0.430
				7	0.310
				12	0.437
			13	2	0.437
				7	0.308
				12	0.432

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	1400	1	2	0.218
				7	0.155
				12	0.219
			7	2	0.748
				7	0.538
				12	0.761
			13	2	0.756
				7	0.544
				12	0.757
8	0	200	1	2	0.029
				7	0.018
				12	0.030
			7	2	0.101
				7	0.067
				12	0.103
			13	2	0.101
				7	0.064
				12	0.101
		800	1	2	0.110
				7	0.078
				12	0.110
			7	2	0.377
				7	0.272
				12	0.379
			13	2	0.385
				7	0.280
				12	0.381
		1400	1	2	0.177
				7	0.127
				12	0.176
			7	2	0.617
				7	0.439
				12	0.616
			13	2	0.611
				7	0.438
				12	0.622
	3	200	1	2	0.033
				7	0.021
				12	0.033
			7	2	0.117
				7	0.072
				12	0.115
			13	2	0.115
				7	0.073
				12	0.115
		800	1	2	0.124
				7	0.088
				12	0.123
			7	2	0.441
				7	0.308
				12	0.430

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3	800	13	2	0.433
				7	0.309
				12	0.432
		1400	1	2	0.198
				7	0.142
				12	0.200
			7	2	0.688
				7	0.491
				12	0.695
			13	2	0.694
				7	0.497
				12	0.692
	6	200	1	2	0.043
				7	0.028
				12	0.043
			7	2	0.155
				7	0.098
				12	0.155
			13	2	0.154
				7	0.096
				12	0.152
		800	1	2	0.163
				7	0.118
				12	0.164
			7	2	0.581
				7	0.411
				12	0.586
			13	2	0.576
				7	0.416
				12	0.579
		1400	1	2	0.266
				7	0.190
				12	0.264
			7	2	0.928
				7	0.662
				12	0.928
			13	2	0.916
				7	0.657
				12	0.924

Appendix O. 4:1 Urban Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.036
				7	0.027
				12	0.022
			7	2	0.186
				7	0.142
				12	0.121
			13	2	0.206
				7	0.160
				12	0.131
		800	1	2	0.140
				7	0.111
				12	0.090
			7	2	0.597
				7	0.475
				12	0.392
			13	2	0.620
				7	0.496
				12	0.399
		1400	1	2	0.247
				7	0.194
				12	0.160
			7	2	1.009
				7	0.804
				12	0.664
			13	2	1.017
				7	0.819
				12	0.662
	3	200	1	2	0.041
				7	0.030
				12	0.024
			7	2	0.209
				7	0.162
				12	0.136
			13	2	0.235
				7	0.189
				12	0.152
		800	1	2	0.159
				7	0.125
				12	0.101
			7	2	0.676
				7	0.533
				12	0.432
			13	2	0.697
				7	0.565
				12	0.447
		1400	1	2	0.276
				7	0.219
				12	0.180
			7	2	1.129
				7	0.908
				12	0.737

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	1.149
				7	0.941
				12	0.767
	6	200	1	2	0.055
				7	0.042
				12	0.033
			7	2	0.271
				7	0.218
				12	0.181
			13	2	0.314
				7	0.243
				12	0.202
		800	1	2	0.211
				7	0.166
				12	0.134
			7	2	0.892
				7	0.716
				12	0.584
			13	2	0.915
				7	0.740
				12	0.602
		1400	1	2	0.369
				7	0.291
				12	0.238
			7	2	1.499
				7	1.211
				12	0.986
			13	2	1.541
				7	1.246
				12	1.012
4	0	200	1	2	0.060
				7	0.043
				12	0.031
			7	2	0.237
				7	0.173
				12	0.120
			13	2	0.246
				7	0.171
				12	0.129
		800	1	2	0.252
				7	0.202
				12	0.164
			7	2	1.010
				7	0.793
				12	0.644
			13	2	1.004
				7	0.811
				12	0.635
		1400	1	2	0.448
				7	0.351
				12	0.285

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	1400	7	2	1.772
				7	1.399
				12	1.130
			13	2	1.767
				7	1.378
				12	1.120
	3	200	1	2	0.068
				7	0.046
				12	0.035
			7	2	0.270
				7	0.191
				12	0.141
			13	2	0.266
				7	0.195
				12	0.144
		800	1	2	0.291
				7	0.230
				12	0.180
			7	2	1.149
				7	0.876
				12	0.726
			13	2	1.151
				7	0.904
				12	0.724
		1400	1	2	0.504
				7	0.396
				12	0.322
			7	2	1.996
				7	1.552
				12	1.268
			13	2	2.006
				7	1.584
				12	1.273
	6	200	1	2	0.091
				7	0.066
				12	0.045
			7	2	0.359
				7	0.257
				12	0.185
			13	2	0.366
				7	0.251
				12	0.187
		800	1	2	0.388
				7	0.300
				12	0.240
			7	2	1.540
				7	1.195
				12	0.959
			13	2	1.540
				7	1.225
				12	0.964

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	1400	1	2	0.669
				7	0.529
				12	0.427
			7	2	2.685
				7	2.115
				12	1.704
			13	2	2.680
				7	2.113
				12	1.681
8	0	200	1	2	0.087
				7	0.061
				12	0.039
			7	2	0.348
				7	0.234
				12	0.159
			13	2	0.344
				7	0.239
				12	0.158
		800	1	2	0.337
				7	0.261
				12	0.208
			7	2	1.311
				7	1.044
				12	0.828
			13	2	1.341
				7	1.030
				12	0.839
		1400	1	2	0.534
				7	0.418
				12	0.339
			7	2	2.146
				7	1.682
				12	1.336
			13	2	2.127
				7	1.662
				12	1.345
	3	200	1	2	0.095
				7	0.065
				12	0.046
			7	2	0.373
				7	0.271
				12	0.181
			13	2	0.387
				7	0.273
				12	0.186
		800	1	2	0.379
				7	0.295
				12	0.235
			7	2	1.519
				7	1.152
				12	0.922

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3	800	13	2	1.502
				7	1.161
				12	0.931
		1400	1	2	0.602
				7	0.476
				12	0.380
			7	2	2.391
				7	1.865
				12	1.512
			13	2	2.362
				7	1.854
				12	1.510
	6	200	1	2	0.125
				7	0.091
				12	0.060
			7	2	0.512
				7	0.362
				12	0.240
			13	2	0.511
				7	0.345
				12	0.244
		800	1	2	0.505
				7	0.393
				12	0.314
			7	2	2.006
				7	1.533
				12	1.249
			13	2	2.015
				7	1.538
				12	1.257
		1400	1	2	0.808
				7	0.632
				12	0.497
			7	2	3.211
				7	2.482
				12	2.002
			13	2	3.177
				7	2.505
				12	1.981

Appendix P. 4:1 Urban Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.059
				7	0.041
				12	0.028
			7	2	0.180
				7	0.123
				12	0.090
			13	2	0.185
				7	0.129
				12	0.089
		800	1	2	0.205
				7	0.146
				12	0.104
			7	2	0.573
				7	0.413
				12	0.295
			13	2	0.563
				7	0.416
				12	0.297
		1400	1	2	0.349
				7	0.253
				12	0.180
			7	2	0.967
				7	0.701
				12	0.501
			13	2	0.963
				7	0.705
				12	0.502
	6	200	1	2	0.087
				7	0.060
				12	0.042
			7	2	0.275
				7	0.195
				12	0.134
			13	2	0.269
				7	0.195
				12	0.134
		800	1	2	0.302
				7	0.224
				12	0.156
			7	2	0.849
				7	0.623
				12	0.436

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	6	800	13	2	0.859
				7	0.625
				12	0.436
		1400	1	2	0.521
				7	0.378
				12	0.271
			7	2	1.447
				7	1.053
				12	0.748
			13	2	1.443
				7	1.047
				12	0.747
	12	200	1	2	0.087
				7	0.059
				12	0.042
			7	2	0.266
				7	0.189
				12	0.133
			13	2	0.275
				7	0.190
				12	0.132
		800	1	2	0.305
				7	0.218
				12	0.155
			7	2	0.849
				7	0.622
				12	0.441
			13	2	0.851
				7	0.615
				12	0.444
		1400	1	2	0.520
				7	0.380
				12	0.273
			7	2	1.446
				7	1.048
				12	0.750
			13	2	1.444
				7	1.042
				12	0.750
3	0	200	1	2	0.052
				7	0.033
				12	0.022

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	7	2	0.141
				7	0.090
				12	0.061
			13	2	0.144
				7	0.091
				12	0.060
		800	1	2	0.192
				7	0.139
				12	0.097
			7	2	0.523
				7	0.379
				12	0.265
			13	2	0.534
				7	0.379
				12	0.266
		1400	1	2	0.327
				7	0.237
				12	0.167
			7	2	0.892
				7	0.643
				12	0.450
			13	2	0.882
				7	0.638
				12	0.452
	6	200	1	2	0.075
				7	0.048
				12	0.032
			7	2	0.215
				7	0.133
				12	0.091
			13	2	0.214
				7	0.138
				12	0.094
		800	1	2	0.289
				7	0.209
				12	0.147
			7	2	0.795
				7	0.568
				12	0.396
			13	2	0.793
				7	0.571
				12	0.399

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	1400	1	2	0.493
				7	0.354
				12	0.250
			7	2	1.324
				7	0.960
				12	0.670
			13	2	1.338
				7	0.958
				12	0.681
	12	200	1	2	0.076
				7	0.048
				12	0.032
			7	2	0.219
				7	0.138
				12	0.091
			13	2	0.220
				7	0.137
				12	0.092
		800	1	2	0.292
				7	0.209
				12	0.145
			7	2	0.798
				7	0.568
				12	0.395
			13	2	0.791
				7	0.569
				12	0.400
		1400	1	2	0.492
				7	0.354
				12	0.249
			7	2	1.327
				7	0.959
				12	0.679
			13	2	1.335
				7	0.959
				12	0.675
6	0	200	1	2	0.150
				7	0.106
				12	0.069
			7	2	0.422
				7	0.291
				12	0.189

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	0	200	13	2	0.428
				7	0.288
				12	0.192
		800	1	2	0.583
				7	0.418
				12	0.297
			7	2	1.573
				7	1.154
				12	0.787
			13	2	1.575
				7	1.144
				12	0.800
		1400	1	2	0.958
				7	0.689
				12	0.486
			7	2	2.582
				7	1.868
				12	1.316
			13	2	2.562
				7	1.853
				12	1.321
	6	200	1	2	0.227
				7	0.151
				12	0.101
			7	2	0.628
				7	0.434
				12	0.292
			13	2	0.635
				7	0.419
				12	0.285
		800	1	2	0.873
				7	0.624
				12	0.448
			7	2	2.377
				7	1.707
				12	1.217
			13	2	2.349
				7	1.702
				12	1.212
		1400	1	2	1.445
				7	1.034
				12	0.727

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	6	1400	7	2	3.865
				7	2.801
				12	1.987
			13	2	3.852
				7	2.776
				12	1.977
	12	200	1	2	0.232
				7	0.157
				12	0.108
			7	2	0.619
				7	0.444
				12	0.290
			13	2	0.616
				7	0.429
				12	0.284
		800	1	2	0.875
				7	0.619
				12	0.443
			7	2	2.357
				7	1.713
				12	1.198
			13	2	2.356
				7	1.694
				12	1.204
		1400	1	2	1.422
				7	1.035
				12	0.728
			7	2	3.878
				7	2.834
				12	1.946
			13	2	3.857
				7	2.818
				12	1.975

Appendix Q. 6:1 Freeway Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.035
				7	0.026
				12	0.021
			7	2	0.047
				7	0.038
				12	0.031
			13	2	0.050
				7	0.039
				12	0.032
		800	1	2	0.128
				7	0.101
				12	0.083
			7	2	0.145
				7	0.112
				12	0.093
			13	2	0.143
				7	0.114
				12	0.093
		1400	1	2	0.223
				7	0.176
				12	0.145
			7	2	0.239
				7	0.191
				12	0.156
			13	2	0.238
				7	0.189
				12	0.155
	2	200	1	2	0.034
				7	0.026
				12	0.021
			7	2	0.049
				7	0.038
				12	0.032
			13	2	0.051
				7	0.040
				12	0.032
		800	1	2	0.129
				7	0.102
				12	0.083
			7	2	0.144
				7	0.114
				12	0.092

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	2	800	13	2	0.145
				7	0.112
				12	0.094
		1400	1	2	0.225
				7	0.181
				12	0.147
			7	2	0.238
				7	0.189
				12	0.156
			13	2	0.238
				7	0.189
				12	0.155
	3	200	1	2	0.040
				7	0.030
				12	0.023
			7	2	0.055
				7	0.042
				12	0.036
			13	2	0.057
				7	0.044
				12	0.036
		800	1	2	0.144
				7	0.115
				12	0.094
			7	2	0.160
				7	0.127
				12	0.105
			13	2	0.164
				7	0.130
				12	0.104
		1400	1	2	0.253
				7	0.201
				12	0.165
			7	2	0.270
				7	0.214
				12	0.176
			13	2	0.270
				7	0.216
				12	0.176
2	0	200	1	2	0.023
				7	0.015
				12	0.010

2	0	200	7	2	0.025
				7	0.018
				12	0.013
			13	2	0.027
				7	0.019
				12	0.014
		800	1	2	0.107
				7	0.080
				12	0.063
			7	2	0.108
				7	0.084
				12	0.067
			13	2	0.110
				7	0.083
				12	0.067
		1400	1	2	0.183
				7	0.146
				12	0.115
			7	2	0.184
				7	0.147
				12	0.118
			13	2	0.188
				7	0.146
				12	0.121
	2	200	1	2	0.024
				7	0.016
				12	0.010
			7	2	0.025
				7	0.017
				12	0.013
			13	2	0.026
				7	0.019
				12	0.014
		800	1	2	0.107
				7	0.082
				12	0.063
			7	2	0.111
				7	0.084
				12	0.068
			13	2	0.111
				7	0.085
				12	0.068

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
2	2	1400	1	2	0.186
				7	0.142
				12	0.116
			7	2	0.187
				7	0.149
				12	0.120
			13	2	0.188
				7	0.146
				12	0.119
	3	200	1	2	0.026
				7	0.017
				12	0.012
			7	2	0.029
				7	0.021
				12	0.015
			13	2	0.029
				7	0.022
				12	0.015
		800	1	2	0.122
				7	0.090
				12	0.070
			7	2	0.121
				7	0.094
				12	0.075
			13	2	0.123
				7	0.096
				12	0.076
		1400	1	2	0.209
				7	0.161
				12	0.132
			7	2	0.210
				7	0.163
				12	0.133
			13	2	0.209
				7	0.164
				12	0.134
3	0	200	1	2	0.026
				7	0.017
				12	0.012
			7	2	0.027
				7	0.017
				12	0.012

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	13	2	0.028
				7	0.017
				12	0.013
		800	1	2	0.113
				7	0.085
				12	0.068
			7	2	0.114
				7	0.087
				12	0.070
			13	2	0.116
				7	0.088
				12	0.069
		1400	1	2	0.190
				7	0.148
				12	0.121
			7	2	0.192
				7	0.149
				12	0.121
			13	2	0.191
				7	0.150
				12	0.123
	2	200	1	2	0.026
				7	0.016
				12	0.011
			7	2	0.028
				7	0.017
				12	0.013
			13	2	0.027
				7	0.018
				12	0.013
		800	1	2	0.112
				7	0.085
				12	0.068
			7	2	0.114
				7	0.086
				12	0.068
			13	2	0.113
				7	0.089
				12	0.068
		1400	1	2	0.192
				7	0.148
				12	0.119

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	2	1400	7	2	0.193
				7	0.150
				12	0.119
			13	2	0.192
				7	0.147
				12	0.119
	3	200	1	2	0.030
				7	0.018
				12	0.013
			7	2	0.030
				7	0.021
				12	0.015
			13	2	0.032
				7	0.019
				12	0.015
		800	1	2	0.128
				7	0.098
				12	0.076
			7	2	0.126
				7	0.098
				12	0.077
			13	2	0.129
				7	0.097
				12	0.076
		1400	1	2	0.213
				7	0.168
				12	0.134
			7	2	0.216
				7	0.168
				12	0.135
			13	2	0.216
				7	0.170
				12	0.136

Appendix R. 6:1 Rural Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.007
				7	0.005
				12	0.003
			7	2	0.008
				7	0.005
				12	0.004
			13	2	0.008
				7	0.005
				12	0.004
		800	1	2	0.024
				7	0.017
				12	0.012
			7	2	0.025
				7	0.018
				12	0.013
			13	2	0.025
				7	0.018
				12	0.013
		1400	1	2	0.042
				7	0.030
				12	0.022
			7	2	0.043
				7	0.031
				12	0.022
			13	2	0.043
				7	0.031
				12	0.022
	3	200	1	2	0.007
				7	0.005
				12	0.004
			7	2	0.009
				7	0.006
				12	0.004
			13	2	0.009
				7	0.006
				12	0.004
		800	1	2	0.027
				7	0.019
				12	0.014
			7	2	0.028
				7	0.020
				12	0.014
			13	2	0.028
				7	0.021
				12	0.015
		1400	1	2	0.047
				7	0.034
				12	0.024
			7	2	0.048
				7	0.035
				12	0.025

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	0.048
				7	0.035
				12	0.025
	6	200	1	2	0.010
				7	0.007
				12	0.005
			7	2	0.012
				7	0.008
				12	0.006
			13	2	0.012
				7	0.008
				12	0.006
		800	1	2	0.036
				7	0.026
				12	0.018
			7	2	0.038
				7	0.027
				12	0.019
			13	2	0.038
				7	0.027
				12	0.019
		1400	1	2	0.062
				7	0.045
				12	0.032
			7	2	0.064
				7	0.046
				12	0.033
			13	2	0.064
				7	0.046
				12	0.033
3	0	200	1	2	0.005
				7	0.003
				12	0.002
			7	2	0.006
				7	0.003
				12	0.002
			13	2	0.005
				7	0.003
				12	0.002
		800	1	2	0.021
				7	0.015
				12	0.011
			7	2	0.022
				7	0.015
				12	0.011
			13	2	0.021
				7	0.015
				12	0.011
		1400	1	2	0.036
				7	0.026
				12	0.018

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	1400	7	2	0.036
				7	0.026
				12	0.018
			13	2	0.036
				7	0.026
				12	0.018
	3	200	1	2	0.006
				7	0.004
				12	0.002
			7	2	0.006
				7	0.004
				12	0.002
			13	2	0.006
				7	0.004
				12	0.002
		800	1	2	0.024
				7	0.017
				12	0.012
			7	2	0.024
				7	0.017
				12	0.012
			13	2	0.024
				7	0.017
				12	0.012
		1400	1	2	0.041
				7	0.029
				12	0.021
			7	2	0.041
				7	0.029
				12	0.021
			13	2	0.040
				7	0.030
				12	0.021
	6	200	1	2	0.008
				7	0.005
				12	0.003
			7	2	0.008
				7	0.005
				12	0.003
			13	2	0.008
				7	0.005
				12	0.003
		800	1	2	0.032
				7	0.023
				12	0.016
			7	2	0.032
				7	0.023
				12	0.016
			13	2	0.033
				7	0.023
				12	0.016

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	1400	1	2	0.054
				7	0.039
				12	0.027
			7	2	0.054
				7	0.039
				12	0.027
			13	2	0.054
				7	0.039
				12	0.028
6	0	200	1	2	0.016
				7	0.010
				12	0.007
			7	2	0.016
				7	0.010
				12	0.007
			13	2	0.016
				7	0.010
				12	0.007
		800	1	2	0.063
				7	0.045
				12	0.032
			7	2	0.064
				7	0.045
				12	0.032
			13	2	0.063
				7	0.046
				12	0.032
		1400	1	2	0.103
				7	0.074
				12	0.052
			7	2	0.104
				7	0.074
				12	0.052
			13	2	0.105
				7	0.074
				12	0.052
	3	200	1	2	0.018
				7	0.012
				12	0.008
			7	2	0.018
				7	0.012
				12	0.008
			13	2	0.018
				7	0.011
				12	0.007
		800	1	2	0.072
				7	0.051
				12	0.035
			7	2	0.071
				7	0.051
				12	0.036

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3	800	13	2	0.072
				7	0.051
				12	0.036
		1400	1	2	0.117
				7	0.084
				12	0.058
			7	2	0.117
				7	0.084
				12	0.058
			13	2	0.116
				7	0.085
				12	0.059
	6	200	1	2	0.023
				7	0.016
				12	0.010
			7	2	0.024
				7	0.016
				12	0.010
			13	2	0.025
				7	0.016
				12	0.010
		800	1	2	0.095
				7	0.069
				12	0.047
			7	2	0.095
				7	0.068
				12	0.047
			13	2	0.096
				7	0.068
				12	0.047
		1400	1	2	0.156
				7	0.111
				12	0.079
			7	2	0.157
				7	0.112
				12	0.078
			13	2	0.156
				7	0.112
				12	0.079

Appendix S. 6:1 Rural Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.014
				7	0.010
				12	0.008
			7	2	0.019
				7	0.015
				12	0.012
			13	2	0.019
				7	0.015
				12	0.013
		800	1	2	0.050
				7	0.040
				12	0.032
			7	2	0.055
				7	0.044
				12	0.036
			13	2	0.055
				7	0.045
				12	0.036
		1400	1	2	0.086
				7	0.070
				12	0.056
			7	2	0.093
				7	0.074
				12	0.060
			13	2	0.094
				7	0.074
				12	0.061
	3	200	1	2	0.015
				7	0.011
				12	0.009
			7	2	0.021
				7	0.016
				12	0.014
			13	2	0.022
				7	0.017
				12	0.014
		800	1	2	0.056
				7	0.044
				12	0.036
			7	2	0.062
				7	0.050
				12	0.040
			13	2	0.063
				7	0.050
				12	0.041
		1400	1	2	0.098
				7	0.078
				12	0.064
			7	2	0.102
				7	0.083
				12	0.067

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	0.105
				7	0.083
				12	0.069
	6	200	1	2	0.020
				7	0.015
				12	0.013
			7	2	0.028
				7	0.023
				12	0.018
			13	2	0.029
				7	0.023
				12	0.019
		800	1	2	0.075
				7	0.059
				12	0.047
			7	2	0.083
				7	0.067
				12	0.054
			13	2	0.084
				7	0.067
				12	0.055
		1400	1	2	0.131
				7	0.104
				12	0.085
			7	2	0.138
				7	0.109
				12	0.091
			13	2	0.140
				7	0.112
				12	0.091
3	0	200	1	2	0.011
				7	0.006
				12	0.005
			7	2	0.011
				7	0.007
				12	0.005
			13	2	0.011
				7	0.007
				12	0.006
		800	1	2	0.044
				7	0.034
				12	0.026
			7	2	0.044
				7	0.035
				12	0.027
			13	2	0.045
				7	0.034
				12	0.027
		1400	1	2	0.075
				7	0.057
				12	0.047

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	1400	7	2	0.074
				7	0.059
				12	0.047
			13	2	0.074
				7	0.058
				12	0.047
	3	200	1	2	0.012
				7	0.007
				12	0.005
			7	2	0.012
				7	0.008
				12	0.006
			13	2	0.013
				7	0.008
				12	0.006
		800	1	2	0.050
				7	0.039
				12	0.030
			7	2	0.050
				7	0.039
				12	0.031
			13	2	0.051
				7	0.039
				12	0.030
		1400	1	2	0.083
				7	0.065
				12	0.052
			7	2	0.084
				7	0.067
				12	0.053
			13	2	0.084
				7	0.067
				12	0.054
	6	200	1	2	0.016
				7	0.010
				12	0.007
			7	2	0.016
				7	0.010
				12	0.008
			13	2	0.016
				7	0.011
				12	0.008
		800	1	2	0.066
				7	0.051
				12	0.040
			7	2	0.067
				7	0.052
				12	0.041
			13	2	0.067
				7	0.051
				12	0.041

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	1400	1	2	0.110
				7	0.087
				12	0.070
			7	2	0.112
				7	0.087
				12	0.072
			13	2	0.111
				7	0.088
				12	0.071
6	0	200	1	2	0.031
				7	0.022
				12	0.015
			7	2	0.030
				7	0.021
				12	0.015
			13	2	0.030
				7	0.022
				12	0.015
		800	1	2	0.129
				7	0.100
				12	0.079
			7	2	0.128
				7	0.099
				12	0.080
			13	2	0.129
				7	0.099
				12	0.080
		1400	1	2	0.208
				7	0.164
				12	0.132
			7	2	0.206
				7	0.165
				12	0.131
			13	2	0.208
				7	0.165
				12	0.131
	3	200	1	2	0.035
				7	0.024
				12	0.018
			7	2	0.034
				7	0.025
				12	0.018
			13	2	0.034
				7	0.024
				12	0.017
		800	1	2	0.143
				7	0.112
				12	0.091
			7	2	0.143
				7	0.112
				12	0.090

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3	800	13	2	0.144
				7	0.111
				12	0.090
		1400	1	2	0.233
				7	0.185
				12	0.148
			7	2	0.236
				7	0.185
				12	0.148
			13	2	0.234
				7	0.184
				12	0.149
	6	200	1	2	0.046
				7	0.032
				12	0.022
			7	2	0.046
				7	0.032
				12	0.024
			13	2	0.049
				7	0.033
				12	0.024
		800	1	2	0.193
				7	0.150
				12	0.118
			7	2	0.191
				7	0.148
				12	0.118
			13	2	0.193
				7	0.150
				12	0.120
		1400	1	2	0.315
				7	0.245
				12	0.199
			7	2	0.312
				7	0.246
				12	0.198
			13	2	0.309
				7	0.246
				12	0.197

Appendix T. 6:1 Rural Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.058
				7	0.040
				12	0.028
			7	2	0.066
				7	0.046
				12	0.032
			13	2	0.067
				7	0.046
				12	0.032
		800	1	2	0.210
				7	0.149
				12	0.107
			7	2	0.215
				7	0.156
				12	0.109
			13	2	0.217
				7	0.156
				12	0.110
		1400	1	2	0.352
				7	0.261
				12	0.185
			7	2	0.361
				7	0.265
				12	0.187
			13	2	0.366
				7	0.262
				12	0.189
	4	200	1	2	0.078
				7	0.051
				12	0.035
			7	2	0.079
				7	0.057
				12	0.040
			13	2	0.083
				7	0.057
				12	0.039
		800	1	2	0.260
				7	0.188
				12	0.131
			7	2	0.267
				7	0.195
				12	0.138

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	4	800	13	2	0.269
				7	0.198
				12	0.138
		1400	1	2	0.441
				7	0.324
				12	0.232
			7	2	0.453
				7	0.336
				12	0.234
			13	2	0.456
				7	0.332
				12	0.237
	8	200	1	2	0.089
				7	0.061
				12	0.042
			7	2	0.099
				7	0.070
				12	0.048
			13	2	0.098
				7	0.069
				12	0.048
		800	1	2	0.307
				7	0.224
				12	0.158
			7	2	0.322
				7	0.235
				12	0.165
			13	2	0.324
				7	0.234
				12	0.166
		1400	1	2	0.531
				7	0.391
				12	0.281
			7	2	0.542
				7	0.399
				12	0.284
			13	2	0.550
				7	0.398
				12	0.284
4	0	200	1	2	0.106
				7	0.076
				12	0.051

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	200	7	2	0.111
				7	0.078
				12	0.053
			13	2	0.117
				7	0.079
				12	0.052
		800	1	2	0.433
				7	0.310
				12	0.216
			7	2	0.429
				7	0.314
				12	0.219
			13	2	0.439
				7	0.310
				12	0.221
		1400	1	2	0.736
				7	0.524
				12	0.373
			7	2	0.723
				7	0.531
				12	0.379
			13	2	0.732
				7	0.533
				12	0.375
	4	200	1	2	0.143
				7	0.095
				12	0.061
			7	2	0.147
				7	0.096
				12	0.065
			13	2	0.144
				7	0.097
				12	0.065
		800	1	2	0.530
				7	0.385
				12	0.270
			7	2	0.542
				7	0.390
				12	0.276
			13	2	0.540
				7	0.389
				12	0.273

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	4	1400	1	2	0.914
				7	0.659
				12	0.470
			7	2	0.921
				7	0.668
				12	0.470
			13	2	0.913
				7	0.671
				12	0.463
	8	200	1	2	0.167
				7	0.115
				12	0.077
			7	2	0.170
				7	0.117
				12	0.077
			13	2	0.172
				7	0.114
				12	0.079
		800	1	2	0.650
				7	0.464
				12	0.330
			7	2	0.640
				7	0.470
				12	0.326
			13	2	0.650
				7	0.465
				12	0.332
		1400	1	2	1.099
				7	0.787
				12	0.561
			7	2	1.098
				7	0.795
				12	0.568
			13	2	1.098
				7	0.799
				12	0.569
8	0	200	1	2	0.155
				7	0.102
				12	0.068
			7	2	0.161
				7	0.104
				12	0.070

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	0	200	13	2	0.160
				7	0.109
				12	0.070
		800	1	2	0.565
				7	0.411
				12	0.282
			7	2	0.572
				7	0.417
				12	0.289
			13	2	0.581
				7	0.412
				12	0.289
		1400	1	2	0.910
				7	0.653
				12	0.468
			7	2	0.920
				7	0.660
				12	0.462
			13	2	0.915
				7	0.664
				12	0.460
	4	200	1	2	0.197
				7	0.131
				12	0.083
			7	2	0.204
				7	0.137
				12	0.083
			13	2	0.202
				7	0.130
				12	0.085
		800	1	2	0.699
				7	0.501
				12	0.360
			7	2	0.719
				7	0.515
				12	0.359
			13	2	0.703
				7	0.515
				12	0.358
		1400	1	2	1.140
				7	0.831
				12	0.575

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	4	1400	7	2	1.133
				7	0.819
				12	0.580
			13	2	1.129
				7	0.827
				12	0.582
	8	200	1	2	0.235
				7	0.157
				12	0.096
			7	2	0.241
				7	0.163
				12	0.103
			13	2	0.245
				7	0.160
				12	0.099
		800	1	2	0.847
				7	0.613
				12	0.428
			7	2	0.850
				7	0.616
				12	0.441
			13	2	0.858
				7	0.618
				12	0.433
		1400	1	2	1.350
				7	0.981
				12	0.692
			7	2	1.359
				7	0.995
				12	0.700
			13	2	1.363
				7	0.988
				12	0.692

Appendix U. 6:1 Urban Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.007
				7	0.005
				12	0.004
			7	2	0.008
				7	0.006
				12	0.004
			13	2	0.008
				7	0.006
				12	0.004
		800	1	2	0.026
				7	0.019
				12	0.014
			7	2	0.028
				7	0.020
				12	0.014
			13	2	0.028
				7	0.020
				12	0.014
		1400	1	2	0.046
				7	0.034
				12	0.024
			7	2	0.047
				7	0.034
				12	0.024
			13	2	0.047
				7	0.034
				12	0.024
	3	200	1	2	0.008
				7	0.006
				12	0.004
			7	2	0.009
				7	0.007
				12	0.005
			13	2	0.009
				7	0.007
				12	0.005
		800	1	2	0.030
				7	0.021
				12	0.015
			7	2	0.031
				7	0.023
				12	0.016
			13	2	0.031
				7	0.023
				12	0.016
		1400	1	2	0.052
				7	0.038
				12	0.027
			7	2	0.053
				7	0.039
				12	0.027

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	0.053
				7	0.039
				12	0.027
	6	200	1	2	0.011
				7	0.008
				12	0.005
			7	2	0.013
				7	0.009
				12	0.006
			13	2	0.013
				7	0.009
				12	0.006
		800	1	2	0.040
				7	0.029
				12	0.020
			7	2	0.042
				7	0.030
				12	0.021
			13	2	0.042
				7	0.030
				12	0.021
		1400	1	2	0.070
				7	0.051
				12	0.036
			7	2	0.071
				7	0.051
				12	0.036
			13	2	0.071
				7	0.052
				12	0.037
4	0	200	1	2	0.012
				7	0.008
				12	0.005
			7	2	0.012
				7	0.008
				12	0.005
			13	2	0.012
				7	0.008
				12	0.005
		800	1	2	0.050
				7	0.036
				12	0.025
			7	2	0.050
				7	0.036
				12	0.025
			13	2	0.050
				7	0.036
				12	0.025
		1400	1	2	0.086
				7	0.061
				12	0.044

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	1400	7	2	0.086
				7	0.062
				12	0.043
			13	2	0.086
				7	0.062
				12	0.043
	3	200	1	2	0.013
				7	0.009
				12	0.006
			7	2	0.014
				7	0.009
				12	0.006
			13	2	0.014
				7	0.009
				12	0.006
		800	1	2	0.056
				7	0.040
				12	0.028
			7	2	0.056
				7	0.040
				12	0.028
			13	2	0.057
				7	0.040
				12	0.028
		1400	1	2	0.097
				7	0.069
				12	0.049
			7	2	0.098
				7	0.070
				12	0.049
			13	2	0.097
				7	0.069
				12	0.049
	6	200	1	2	0.018
				7	0.012
				12	0.008
			7	2	0.018
				7	0.012
				12	0.008
			13	2	0.019
				7	0.012
				12	0.008
		800	1	2	0.074
				7	0.053
				12	0.037
			7	2	0.076
				7	0.054
				12	0.037
			13	2	0.075
				7	0.053
				12	0.038

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	1400	1	2	0.130
				7	0.093
				12	0.065
			7	2	0.129
				7	0.093
				12	0.066
			13	2	0.129
				7	0.093
				12	0.065
8	0	200	1	2	0.017
				7	0.011
				12	0.007
			7	2	0.017
				7	0.011
				12	0.007
			13	2	0.018
				7	0.011
				12	0.007
		800	1	2	0.067
				7	0.047
				12	0.033
			7	2	0.066
				7	0.047
				12	0.033
			13	2	0.066
				7	0.047
				12	0.033
		1400	1	2	0.106
				7	0.075
				12	0.053
			7	2	0.105
				7	0.075
				12	0.053
			13	2	0.107
				7	0.076
				12	0.053
	3	200	1	2	0.019
				7	0.012
				12	0.008
			7	2	0.019
				7	0.013
				12	0.008
			13	2	0.020
				7	0.012
				12	0.008
		800	1	2	0.074
				7	0.053
				12	0.037
			7	2	0.075
				7	0.053
				12	0.037

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3	800	13	2	0.074
				7	0.054
				12	0.037
		1400	1	2	0.118
				7	0.086
				12	0.060
			7	2	0.120
				7	0.085
				12	0.060
			13	2	0.119
				7	0.085
				12	0.059
	6	200	1	2	0.027
				7	0.017
				12	0.010
			7	2	0.026
				7	0.017
				12	0.011
			13	2	0.026
				7	0.017
				12	0.010
		800	1	2	0.099
				7	0.071
				12	0.049
			7	2	0.100
				7	0.071
				12	0.049
			13	2	0.099
				7	0.071
				12	0.050
		1400	1	2	0.160
				7	0.113
				12	0.080
			7	2	0.158
				7	0.113
				12	0.079
			13	2	0.159
				7	0.114
				12	0.080

Appendix V. 6:1 Urban Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.014
				7	0.011
				12	0.009
			7	2	0.019
				7	0.016
				12	0.013
			13	2	0.020
				7	0.016
				12	0.013
		800	1	2	0.054
				7	0.043
				12	0.035
			7	2	0.060
				7	0.047
				12	0.039
			13	2	0.060
				7	0.048
				12	0.039
		1400	1	2	0.095
				7	0.075
				12	0.062
			7	2	0.100
				7	0.079
				12	0.065
			13	2	0.101
				7	0.081
				12	0.066
	3	200	1	2	0.016
				7	0.013
				12	0.010
			7	2	0.022
				7	0.018
				12	0.014
			13	2	0.023
				7	0.018
				12	0.015
		800	1	2	0.062
				7	0.049
				12	0.039
			7	2	0.067
				7	0.053
				12	0.043
			13	2	0.068
				7	0.054
				12	0.044
		1400	1	2	0.106
				7	0.085
				12	0.070
			7	2	0.112
				7	0.090
				12	0.073

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	0.115
				7	0.091
				12	0.074
	6	200	1	2	0.022
				7	0.016
				12	0.013
			7	2	0.029
				7	0.023
				12	0.019
			13	2	0.031
				7	0.024
				12	0.020
		800	1	2	0.082
				7	0.064
				12	0.052
			7	2	0.089
				7	0.071
				12	0.059
			13	2	0.091
				7	0.072
				12	0.058
		1400	1	2	0.142
				7	0.112
				12	0.092
			7	2	0.150
				7	0.120
				12	0.098
			13	2	0.151
				7	0.121
				12	0.098
4	0	200	1	2	0.023
				7	0.017
				12	0.011
			7	2	0.023
				7	0.017
				12	0.012
			13	2	0.023
				7	0.017
				12	0.013
		800	1	2	0.097
				7	0.078
				12	0.063
			7	2	0.099
				7	0.078
				12	0.062
			13	2	0.100
				7	0.078
				12	0.062
		1400	1	2	0.171
				7	0.136
				12	0.109

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	1400	7	2	0.171
				7	0.136
				12	0.110
			13	2	0.172
				7	0.138
				12	0.108
	3	200	1	2	0.026
				7	0.018
				12	0.014
			7	2	0.027
				7	0.019
				12	0.014
			13	2	0.027
				7	0.020
				12	0.014
		800	1	2	0.112
				7	0.088
				12	0.070
			7	2	0.110
				7	0.087
				12	0.070
			13	2	0.111
				7	0.088
				12	0.070
		1400	1	2	0.194
				7	0.152
				12	0.124
			7	2	0.192
				7	0.152
				12	0.122
			13	2	0.193
				7	0.155
				12	0.124
	6	200	1	2	0.035
				7	0.025
				12	0.017
			7	2	0.035
				7	0.025
				12	0.018
			13	2	0.035
				7	0.026
				12	0.019
		800	1	2	0.148
				7	0.114
				12	0.092
			7	2	0.149
				7	0.117
				12	0.094
			13	2	0.149
				7	0.119
				12	0.093

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	1400	1	2	0.260
				7	0.202
				12	0.163
			7	2	0.259
				7	0.202
				12	0.166
			13	2	0.256
				7	0.205
				12	0.163
8	0	200	1	2	0.033
				7	0.023
				12	0.016
			7	2	0.032
				7	0.023
				12	0.016
			13	2	0.034
				7	0.023
				12	0.016
		800	1	2	0.130
				7	0.100
				12	0.081
			7	2	0.131
				7	0.101
				12	0.082
			13	2	0.130
				7	0.101
				12	0.080
		1400	1	2	0.205
				7	0.161
				12	0.132
			7	2	0.208
				7	0.161
				12	0.130
			13	2	0.208
				7	0.163
				12	0.130
	3	200	1	2	0.038
				7	0.026
				12	0.018
			7	2	0.038
				7	0.025
				12	0.018
			13	2	0.038
				7	0.027
				12	0.018
		800	1	2	0.146
				7	0.112
				12	0.091
			7	2	0.145
				7	0.114
				12	0.092

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3	800	13	2	0.147
				7	0.113
				12	0.092
		1400	1	2	0.232
				7	0.180
				12	0.147
			7	2	0.233
				7	0.182
				12	0.146
			13	2	0.231
				7	0.182
				12	0.148
	6	200	1	2	0.051
				7	0.034
				12	0.024
			7	2	0.050
				7	0.034
				12	0.023
			13	2	0.051
				7	0.034
				12	0.023
		800	1	2	0.196
				7	0.151
				12	0.122
			7	2	0.194
				7	0.152
				12	0.120
			13	2	0.196
				7	0.151
				12	0.120
		1400	1	2	0.312
				7	0.241
				12	0.195
			7	2	0.308
				7	0.243
				12	0.198
			13	2	0.312
				7	0.241
				12	0.196

Appendix W. Guardrail Freeway Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	1.691
				7	1.160
				12	0.917
			7	2	2.285
				7	1.647
				12	1.409
			13	2	2.479
				7	1.766
				12	1.384
		800	1	2	4.974
				7	4.150
				12	3.282
			7	2	5.866
				7	4.561
				12	3.584
			13	2	6.483
				7	4.859
				12	3.919
		1400	1	2	8.743
				7	6.724
				12	5.261
			7	2	9.282
				7	7.487
				12	5.979
			13	2	10.007
				7	8.115
				12	6.589
	2	200	1	2	1.544
				7	1.042
				12	0.944
			7	2	2.281
				7	1.642
				12	1.229
			13	2	2.427
				7	1.823
				12	1.407
		800	1	2	4.970
				7	3.915
				12	3.142
			7	2	5.986
				7	4.531
				12	3.558

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	2	800	13	2	6.337
				7	4.949
				12	3.901
		1400	1	2	8.698
				7	6.832
				12	5.430
			7	2	9.527
				7	7.258
				12	5.949
			13	2	9.845
				7	7.869
				12	6.529
	3	200	1	2	1.807
				7	1.329
				12	1.022
			7	2	2.690
				7	1.700
				12	1.445
			13	2	2.765
				7	2.212
				12	1.590
		800	1	2	5.625
				7	4.451
				12	3.559
			7	2	6.654
				7	5.044
				12	4.070
			13	2	7.136
				7	5.273
				12	4.444
		1400	1	2	9.724
				7	7.567
				12	6.508
			7	2	10.630
				7	8.362
				12	6.998
			13	2	11.316
				7	8.826
				12	7.029
2	0	200	1	2	1.390
				7	1.006
				12	0.862

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
2	0	200	7	2	1.996
				7	1.350
				12	1.046
			13	2	2.158
				7	1.541
				12	1.185
		800	1	2	4.668
				7	3.740
				12	2.812
			7	2	5.519
				7	4.238
				12	3.301
			13	2	5.792
				7	4.325
				12	3.461
		1400	1	2	7.942
				7	6.099
				12	5.072
			7	2	8.831
				7	6.977
				12	5.418
			13	2	9.269
				7	7.002
				12	5.898
	2	200	1	2	1.402
				7	1.095
				12	0.807
			7	2	2.146
				7	1.458
				12	1.141
			13	2	2.181
				7	1.636
				12	1.204
		800	1	2	4.719
				7	3.732
				12	2.999
			7	2	5.357
				7	4.147
				12	3.354
			13	2	5.669
				7	4.299
				12	3.391

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
2	2	1400	1	2	8.076
				7	6.215
				12	5.036
			7	2	8.945
				7	6.742
				12	5.557
			13	2	9.204
				7	7.111
				12	5.722
	3	200	1	2	1.627
				7	1.134
				12	0.940
			7	2	2.277
				7	1.597
				12	1.290
			13	2	2.533
				7	1.902
				12	1.349
		800	1	2	5.255
				7	4.230
				12	3.436
			7	2	5.980
				7	4.671
				12	3.804
			13	2	6.518
				7	4.903
				12	4.066
		1400	1	2	9.032
				7	6.804
				12	5.692
			7	2	9.803
				7	7.592
				12	6.172
			13	2	10.501
				7	8.010
				12	6.690
3	0	200	1	2	1.741
				7	1.163
				12	0.973
			7	2	2.495
				7	1.694
				12	1.255

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	13	2	2.738
				7	1.932
				12	1.420
		800	1	2	5.449
				7	4.213
				12	3.457
			7	2	6.278
				7	4.700
				12	3.836
			13	2	6.487
				7	4.997
				12	3.962
		1400	1	2	9.455
				7	7.100
				12	5.815
			7	2	10.233
				7	7.779
				12	6.309
			13	2	10.376
				7	7.945
				12	6.512
	2	200	1	2	1.718
				7	1.208
				12	1.020
			7	2	2.297
				7	1.773
				12	1.313
			13	2	2.544
				7	1.789
				12	1.386
		800	1	2	5.541
				7	4.261
				12	3.438
			7	2	6.234
				7	4.722
				12	3.736
			13	2	6.404
				7	4.922
				12	3.735
		1400	1	2	9.635
				7	7.404
				12	5.760

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	2	1400	7	2	10.072
				7	7.929
				12	6.378
			13	2	10.449
				7	8.171
				12	6.440
	3	200	1	2	2.006
				7	1.324
				12	1.087
			7	2	2.704
				7	1.773
				12	1.466
			13	2	2.961
				7	2.122
				12	1.628
		800	1	2	6.092
				7	4.696
				12	3.889
			7	2	7.056
				7	5.419
				12	4.168
			13	2	7.532
				7	5.599
				12	4.458
		1400	1	2	10.548
				7	8.056
				12	6.617
			7	2	11.526
				7	8.939
				12	7.348
			13	2	11.641
				7	9.153
				12	7.038

Appendix X. Guardrail Rural Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.453
				7	0.324
				12	0.194
			7	2	0.659
				7	0.429
				12	0.294
			13	2	0.715
				7	0.496
				12	0.319
		800	1	2	1.551
				7	1.027
				12	0.804
			7	2	1.754
				7	1.234
				12	0.824
			13	2	1.803
				7	1.316
				12	0.922
		1400	1	2	2.519
				7	1.873
				12	1.321
			7	2	2.740
				7	1.995
				12	1.424
			13	2	3.066
				7	2.025
				12	1.504
	3	200	1	2	0.554
				7	0.377
				12	0.235
			7	2	0.767
				7	0.487
				12	0.340
			13	2	0.832
				7	0.537
				12	0.352
		800	1	2	1.672
				7	1.231
				12	0.856
			7	2	1.974
				7	1.324
				12	0.972
			13	2	1.975
				7	1.445
				12	1.016
		1400	1	2	2.799
				7	1.987
				12	1.452
			7	2	3.274
				7	2.190
				12	1.624

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	3.275
				7	2.346
				12	1.642
	6	200	1	2	0.712
				7	0.489
				12	0.333
			7	2	0.993
				7	0.667
				12	0.428
			13	2	1.163
				7	0.764
				12	0.471
		800	1	2	2.208
				7	1.626
				12	1.124
			7	2	2.610
				7	1.771
				12	1.296
			13	2	2.732
				7	1.900
				12	1.341
		1400	1	2	3.928
				7	2.801
				12	1.985
			7	2	4.102
				7	3.001
				12	2.127
			13	2	4.313
				7	3.156
				12	2.164
3	0	200	1	2	0.518
				7	0.348
				12	0.239
			7	2	0.777
				7	0.491
				12	0.323
			13	2	0.826
				7	0.516
				12	0.349
		800	1	2	1.604
				7	1.184
				12	0.840
			7	2	1.831
				7	1.314
				12	0.919
			13	2	1.934
				7	1.377
				12	0.980
		1400	1	2	2.758
				7	2.026
				12	1.414

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	1400	7	2	3.008
				7	2.149
				12	1.496
			13	2	3.086
				7	2.249
				12	1.594
	3	200	1	2	0.655
				7	0.413
				12	0.303
			7	2	0.836
				7	0.537
				12	0.369
			13	2	0.927
				7	0.611
				12	0.415
		800	1	2	1.812
				7	1.377
				12	0.924
			7	2	2.135
				7	1.476
				12	1.066
			13	2	2.261
				7	1.558
				12	1.105
		1400	1	2	3.103
				7	2.284
				12	1.525
			7	2	3.426
				7	2.356
				12	1.695
			13	2	3.515
				7	2.562
				12	1.745
	6	200	1	2	0.782
				7	0.499
				12	0.339
			7	2	1.128
				7	0.710
				12	0.453
			13	2	1.251
				7	0.808
				12	0.531
		800	1	2	2.523
				7	1.817
				12	1.226
			7	2	2.833
				7	1.903
				12	1.385
			13	2	2.989
				7	2.094
				12	1.500

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	1400	1	2	4.189
				7	2.975
				12	2.070
			7	2	4.578
				7	3.310
				12	2.290
			13	2	4.667
				7	3.355
				12	2.355
6	0	200	1	2	1.964
				7	1.327
				12	0.869
			7	2	2.778
				7	1.766
				12	1.248
			13	2	3.154
				7	2.079
				12	1.298
		800	1	2	6.199
				7	4.319
				12	3.096
			7	2	6.944
				7	4.600
				12	3.446
			13	2	7.382
				7	5.013
				12	3.525
		1400	1	2	10.271
				7	7.348
				12	5.238
			7	2	11.355
				7	7.872
				12	5.519
			13	2	11.950
				7	8.033
				12	5.794
	3	200	1	2	2.153
				7	1.504
				12	1.085
			7	2	3.225
				7	2.074
				12	1.363
			13	2	3.434
				7	2.288
				12	1.539
		800	1	2	6.897
				7	4.700
				12	3.338
			7	2	8.231
				7	5.430
				12	3.812

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3	800	13	2	8.373
				7	5.770
				12	3.931
		1400	1	2	11.994
				7	8.408
				12	5.847
			7	2	12.703
				7	8.864
				12	6.357
			13	2	13.251
				7	9.463
				12	6.616
	6	200	1	2	3.021
				7	1.865
				12	1.355
			7	2	4.477
				7	2.818
				12	1.831
			13	2	4.562
				7	3.158
				12	2.060
		800	1	2	8.838
				7	6.716
				12	4.428
			7	2	10.267
				7	6.912
				12	5.153
			13	2	10.912
				7	7.766
				12	5.491
		1400	1	2	15.714
				7	11.259
				12	7.792
			7	2	17.213
				7	12.500
				12	8.481
			13	2	17.353
				7	12.474
				12	8.643

Appendix Y. Guardrail Rural Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.993
				7	0.633
				12	0.594
			7	2	1.410
				7	0.983
				12	0.808
			13	2	1.635
				7	1.182
				12	0.874
		800	1	2	3.205
				7	2.489
				12	1.888
			7	2	3.637
				7	2.873
				12	2.256
			13	2	3.876
				7	3.001
				12	2.392
		1400	1	2	5.315
				7	4.210
				12	3.443
			7	2	5.956
				7	4.684
				12	3.597
			13	2	5.955
				7	4.967
				12	3.963
	3	200	1	2	1.075
				7	0.845
				12	0.613
			7	2	1.506
				7	1.055
				12	0.920
			13	2	1.791
				7	1.352
				12	0.997
		800	1	2	3.376
				7	2.792
				12	2.361
			7	2	4.038
				7	3.058
				12	2.485
			13	2	4.437
				7	3.214
				12	2.646
		1400	1	2	5.926
				7	4.697
				12	3.906
			7	2	6.691
				7	5.166
				12	4.184

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	6.789
				7	5.460
				12	4.416
	6	200	1	2	1.489
				7	1.087
				12	0.788
			7	2	2.238
				7	1.461
				12	1.117
			13	2	2.363
				7	1.618
				12	1.278
		800	1	2	4.569
				7	3.681
				12	3.042
			7	2	5.526
				7	4.094
				12	3.320
			13	2	5.991
				7	4.420
				12	3.810
		1400	1	2	8.022
				7	6.519
				12	4.879
			7	2	8.744
				7	6.847
				12	5.713
			13	2	9.102
				7	7.307
				12	5.973
3	0	200	1	2	1.039
				7	0.750
				12	0.569
			7	2	1.421
				7	1.061
				12	0.793
			13	2	1.629
				7	1.174
				12	0.875
		800	1	2	3.254
				7	2.676
				12	2.105
			7	2	3.819
				7	2.822
				12	2.355
			13	2	4.034
				7	2.884
				12	2.467
		1400	1	2	5.842
				7	4.496
				12	3.765

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	1400	7	2	6.072
				7	4.868
				12	4.028
			13	2	6.208
				7	4.938
				12	3.910
	3	200	1	2	1.193
				7	0.836
				12	0.623
			7	2	1.786
				7	1.190
				12	0.895
			13	2	1.852
				7	1.219
				12	0.937
		800	1	2	3.799
				7	2.905
				12	2.310
			7	2	4.304
				7	3.304
				12	2.689
			13	2	4.406
				7	3.467
				12	2.757
		1400	1	2	6.512
				7	4.957
				12	4.059
			7	2	7.080
				7	5.349
				12	4.335
			13	2	7.128
				7	5.662
				12	4.624
	6	200	1	2	1.539
				7	1.125
				12	0.890
			7	2	2.278
				7	1.496
				12	1.216
			13	2	2.543
				7	1.735
				12	1.293
		800	1	2	5.086
				7	3.853
				12	3.229
			7	2	5.780
				7	4.397
				12	3.416
			13	2	5.876
				7	4.709
				12	3.645

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	1400	1	2	8.544
				7	6.702
				12	5.471
			7	2	9.289
				7	7.093
				12	5.815
			13	2	9.811
				7	7.528
				12	6.068
6	0	200	1	2	3.850
				7	2.643
				12	2.067
			7	2	5.208
				7	3.471
				12	2.767
			13	2	5.565
				7	3.822
				12	2.995
		800	1	2	11.565
				7	9.145
				12	7.582
			7	2	13.679
				7	10.481
				12	8.152
			13	2	13.655
				7	10.642
				12	8.502
		1400	1	2	20.223
				7	15.510
				12	12.841
			7	2	20.966
				7	16.947
				12	13.547
			13	2	22.687
				7	17.575
				12	13.633
	3	200	1	2	4.361
				7	2.883
				12	2.315
			7	2	5.268
				7	3.962
				12	3.056
			13	2	6.157
				7	4.435
				12	3.374
		800	1	2	13.684
				7	10.293
				12	8.101
			7	2	15.610
				7	11.634
				12	9.100

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	3	800	13	2	15.403
				7	11.707
				12	9.568
		1400	1	2	23.399
				7	17.764
				12	14.711
			7	2	25.684
				7	19.566
				12	15.436
			13	2	25.079
				7	19.231
				12	15.673
	6	200	1	2	5.421
				7	3.855
				12	3.084
			7	2	8.024
				7	5.579
				12	4.395
			13	2	8.413
				7	5.960
				12	4.319
		800	1	2	18.005
				7	13.042
				12	11.502
			7	2	19.985
				7	15.193
				12	12.139
			13	2	21.384
				7	16.021
				12	12.792
		1400	1	2	30.665
				7	23.389
				12	18.647
			7	2	32.627
				7	25.000
				12	20.498
			13	2	33.379
				7	25.575
				12	21.623

Appendix Z. Guardrail Rural Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	4.632
				7	3.188
				12	2.265
			7	2	7.030
				7	4.552
				12	3.044
			13	2	7.680
				7	5.566
				12	3.583
		800	1	2	13.752
				7	10.652
				12	7.369
			7	2	16.537
				7	12.478
				12	8.274
			13	2	17.646
				7	12.871
				12	9.096
		1400	1	2	24.315
				7	18.086
				12	12.771
			7	2	27.937
				7	19.166
				12	13.764
			13	2	27.883
				7	21.128
				12	14.240
	4	200	1	2	5.969
				7	4.451
				12	2.942
			7	2	8.622
				7	5.691
				12	3.903
			13	2	9.066
				7	6.497
				12	4.601
		800	1	2	18.186
				7	13.255
				12	9.482
			7	2	20.996
				7	14.777
				12	10.733

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	4	800	13	2	22.636
				7	16.501
				12	10.726
		1400	1	2	31.140
				7	22.284
				12	15.673
			7	2	33.947
				7	24.162
				12	17.386
			13	2	35.126
				7	25.765
				12	18.070
	8	200	1	2	7.041
				7	5.116
				12	3.369
			7	2	10.796
				7	7.111
				12	4.694
			13	2	12.166
				7	7.914
				12	5.646
		800	1	2	22.190
				7	15.802
				12	11.336
			7	2	25.210
				7	17.217
				12	12.335
			13	2	26.629
				7	18.743
				12	13.302
		1400	1	2	36.024
				7	26.256
				12	18.523
			7	2	39.563
				7	30.035
				12	20.493
			13	2	42.682
				7	30.568
				12	22.111
4	0	200	1	2	12.332
				7	8.478
				12	6.341

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	200	7	2	18.689
				7	12.296
				12	8.618
			13	2	20.744
				7	15.114
				12	9.620
		800	1	2	39.760
				7	28.451
				12	20.028
			7	2	44.976
				7	30.998
				12	21.354
			13	2	48.569
				7	34.615
				12	23.685
		1400	1	2	63.035
				7	45.918
				12	33.060
			7	2	72.085
				7	49.950
				12	36.341
			13	2	76.223
				7	55.014
				12	37.042
	4	200	1	2	16.192
				7	10.652
				12	7.590
			7	2	23.130
				7	15.866
				12	10.775
			13	2	26.325
				7	18.155
				12	12.683
		800	1	2	47.198
				7	35.704
				12	23.979
			7	2	55.900
				7	39.385
				12	28.553
			13	2	59.724
				7	42.257
				12	30.217

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	4	1400	1	2	82.691
				7	57.293
				12	41.181
			7	2	90.353
				7	64.669
				12	45.178
			13	2	93.248
				7	66.942
				12	47.234
	8	200	1	2	19.138
				7	13.002
				12	9.748
			7	2	29.147
				7	19.999
				12	11.855
			13	2	30.752
				7	21.212
				12	14.694
		800	1	2	58.443
				7	39.834
				12	28.244
			7	2	67.996
				7	47.633
				12	33.483
			13	2	68.293
				7	50.263
				12	35.870
		1400	1	2	94.826
				7	70.234
				12	50.609
			7	2	105.961
				7	75.923
				12	55.441
			13	2	110.311
				7	79.624
				12	55.414
8	0	200	1	2	23.112
				7	15.908
				12	10.441
			7	2	34.553
				7	24.187
				12	16.565

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	0	200	13	2	39.491
				7	25.284
				12	18.906
		800	1	2	70.847
				7	50.011
				12	36.306
			7	2	85.211
				7	57.951
				12	41.674
			13	2	87.503
				7	62.883
				12	44.022
		1400	1	2	121.997
				7	85.968
				12	60.582
			7	2	138.441
				7	95.522
				12	66.053
			13	2	139.000
				7	100.406
				12	69.126
	4	200	1	2	28.120
				7	20.361
				12	13.188
			7	2	43.114
				7	29.014
				12	19.748
			13	2	48.541
				7	31.903
				12	22.492
		800	1	2	90.153
				7	64.425
				12	45.696
			7	2	103.842
				7	70.677
				12	51.789
			13	2	110.546
				7	79.977
				12	54.431
		1400	1	2	149.448
				7	105.998
				12	76.239

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	4	1400	7	2	170.211
				7	119.056
				12	83.480
			13	2	184.570
				7	128.995
				12	86.272
	8	200	1	2	34.773
				7	23.686
				12	16.644
			7	2	52.268
				7	36.266
				12	23.266
			13	2	58.643
				7	39.535
				12	26.508
		800	1	2	105.729
				7	76.293
				12	55.598
			7	2	125.835
				7	88.474
				12	60.418
			13	2	130.538
				7	95.709
				12	65.928
		1400	1	2	184.573
				7	132.285
				12	88.622
			7	2	201.700
				7	137.197
				12	99.997
			13	2	208.945
				7	151.200
				12	106.857

Appendix AA. Guardrail Urban Arterial Undivided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.423
				7	0.299
				12	0.200
			7	2	0.606
				7	0.396
				12	0.273
			13	2	0.630
				7	0.425
				12	0.294
		800	1	2	1.316
				7	0.938
				12	0.674
			7	2	1.535
				7	1.102
				12	0.735
			13	2	1.586
				7	1.093
				12	0.801
		1400	1	2	2.200
				7	1.660
				12	1.146
			7	2	2.522
				7	1.781
				12	1.227
			13	2	2.525
				7	1.860
				12	1.307
	3	200	1	2	0.470
				7	0.316
				12	0.223
			7	2	0.652
				7	0.442
				12	0.303
			13	2	0.709
				7	0.463
				12	0.335
		800	1	2	1.471
				7	1.080
				12	0.773
			7	2	1.720
				7	1.213
				12	0.865
			13	2	1.782
				7	1.293
				12	0.892
		1400	1	2	2.539
				7	1.774
				12	1.332
			7	2	2.789
				7	1.926
				12	1.372

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	2.845
				7	2.050
				12	1.444
	6	200	1	2	0.647
				7	0.422
				12	0.293
			7	2	0.909
				7	0.589
				12	0.391
			13	2	0.999
				7	0.659
				12	0.462
		800	1	2	2.028
				7	1.456
				12	1.000
			7	2	2.300
				7	1.639
				12	1.140
			13	2	2.454
				7	1.716
				12	1.194
		1400	1	2	3.313
				7	2.398
				12	1.773
			7	2	3.712
				7	2.685
				12	1.901
			13	2	3.915
				7	2.708
				12	2.007
4	0	200	1	2	1.045
				7	0.691
				12	0.483
			7	2	1.481
				7	1.008
				12	0.651
			13	2	1.602
				7	1.034
				12	0.719
		800	1	2	3.285
				7	2.315
				12	1.678
			7	2	3.779
				7	2.637
				12	1.843
			13	2	3.927
				7	2.755
				12	1.916
		1400	1	2	5.508
				7	3.899
				12	2.818

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	1400	7	2	6.030
				7	4.272
				12	3.011
			13	2	6.260
				7	4.406
				12	3.121
	3	200	1	2	1.157
				7	0.780
				12	0.504
			7	2	1.632
				7	1.096
				12	0.740
			13	2	1.803
				7	1.222
				12	0.785
		800	1	2	3.687
				7	2.683
				12	1.886
			7	2	4.263
				7	2.973
				12	2.108
			13	2	4.375
				7	3.059
				12	2.164
		1400	1	2	6.192
				7	4.422
				12	3.178
			7	2	6.766
				7	4.857
				12	3.308
			13	2	6.938
				7	4.943
				12	3.487
	6	200	1	2	1.570
				7	1.018
				12	0.693
			7	2	2.243
				7	1.420
				12	0.984
			13	2	2.406
				7	1.629
				12	1.095
		800	1	2	4.896
				7	3.489
				12	2.450
			7	2	5.757
				7	3.936
				12	2.710
			13	2	5.997
				7	4.107
				12	2.815

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	1400	1	2	8.327
				7	5.994
				12	4.296
			7	2	8.909
				7	6.393
				12	4.494
			13	2	9.068
				7	6.526
				12	4.583
8	0	200	1	2	1.830
				7	1.178
				12	0.829
			7	2	2.678
				7	1.734
				12	1.166
			13	2	2.902
				7	1.905
				12	1.281
		800	1	2	5.791
				7	4.047
				12	2.912
			7	2	6.757
				7	4.539
				12	3.211
			13	2	6.935
				7	4.841
				12	3.464
		1400	1	2	9.793
				7	6.940
				12	5.018
			7	2	10.627
				7	7.465
				12	5.249
			13	2	10.882
				7	7.891
				12	5.427
	3	200	1	2	1.956
				7	1.341
				12	0.939
			7	2	3.057
				7	1.978
				12	1.263
			13	2	3.235
				7	2.154
				12	1.432
		800	1	2	6.457
				7	4.550
				12	3.192
			7	2	7.528
				7	5.220
				12	3.561

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3	800	13	2	7.692
				7	5.344
				12	3.713
		1400	1	2	10.968
				7	7.879
				12	5.484
			7	2	11.909
				7	8.471
				12	5.940
			13	2	12.387
				7	8.623
				12	6.174
	6	200	1	2	2.788
				7	1.902
				12	1.216
			7	2	4.086
				7	2.605
				12	1.679
			13	2	4.287
				7	2.970
				12	1.878
		800	1	2	8.530
				7	5.979
				12	4.421
			7	2	10.000
				7	6.899
				12	4.767
			13	2	10.370
				7	7.261
				12	5.008
		1400	1	2	14.914
				7	10.238
				12	7.340
			7	2	15.952
				7	11.227
				12	7.951
			13	2	16.404
				7	11.660
				12	8.035

Appendix BB. Guardrail Urban Arterial Divided Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	0.881
				7	0.623
				12	0.453
			7	2	1.289
				7	0.865
				12	0.674
			13	2	1.346
				7	0.992
				12	0.743
		800	1	2	2.733
				7	2.098
				12	1.720
			7	2	3.291
				7	2.450
				12	1.936
			13	2	3.393
				7	2.631
				12	2.045
		1400	1	2	4.649
				7	3.709
				12	2.913
			7	2	5.126
				7	3.923
				12	3.267
			13	2	5.402
				7	4.119
				12	3.436
	3	200	1	2	0.944
				7	0.690
				12	0.548
			7	2	1.345
				7	0.976
				12	0.755
			13	2	1.428
				7	1.066
				12	0.863
		800	1	2	2.969
				7	2.513
				12	1.878
			7	2	3.470
				7	2.770
				12	2.178
			13	2	3.805
				7	2.898
				12	2.359
		1400	1	2	5.049
				7	4.098
				12	3.292
			7	2	5.724
				7	4.360
				12	3.664

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	3	1400	13	2	5.895
				7	4.726
				12	3.894
	6	200	1	2	1.274
				7	0.928
				12	0.675
			7	2	1.811
				7	1.311
				12	1.031
			13	2	2.088
				7	1.447
				12	1.126
		800	1	2	4.050
				7	3.175
				12	2.596
			7	2	4.588
				7	3.637
				12	2.972
			13	2	5.116
				7	3.853
				12	3.179
		1400	1	2	7.018
				7	5.445
				12	4.452
			7	2	7.676
				7	6.058
				12	4.818
			13	2	7.953
				7	6.263
				12	5.098
4	0	200	1	2	2.037
				7	1.469
				12	1.132
			7	2	2.812
				7	2.055
				12	1.520
			13	2	3.085
				7	2.160
				12	1.656
		800	1	2	6.471
				7	5.043
				12	4.028
			7	2	7.389
				7	5.603
				12	4.546
			13	2	7.864
				7	5.835
				12	4.558
		1400	1	2	10.856
				7	8.545
				12	6.976

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	0	1400	7	2	11.816
				7	9.244
				12	7.328
			13	2	12.093
				7	9.611
				12	7.656
	3	200	1	2	2.198
				7	1.565
				12	1.281
			7	2	3.094
				7	2.300
				12	1.689
			13	2	3.449
				7	2.454
				12	1.931
		800	1	2	7.361
				7	5.711
				12	4.415
			7	2	8.326
				7	6.395
				12	5.032
			13	2	8.517
				7	6.426
				12	5.267
		1400	1	2	12.341
				7	9.683
				12	7.897
			7	2	13.669
				7	10.150
				12	8.256
			13	2	13.488
				7	10.839
				12	8.533
	6	200	1	2	2.983
				7	2.251
				12	1.646
			7	2	4.413
				7	2.936
				12	2.338
			13	2	4.586
				7	3.218
				12	2.419
		800	1	2	9.991
				7	7.536
				12	6.275
			7	2	10.784
				7	8.457
				12	6.798
			13	2	11.503
				7	9.184
				12	6.905

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
4	6	1400	1	2	16.288
				7	12.782
				12	10.169
			7	2	17.791
				7	13.732
				12	11.176
			13	2	17.997
				7	14.074
				12	11.118
8	0	200	1	2	3.358
				7	2.344
				12	1.679
			7	2	4.682
				7	3.270
				12	2.623
			13	2	4.979
				7	3.675
				12	2.639
		800	1	2	10.788
				7	8.181
				12	6.545
			7	2	12.402
				7	8.844
				12	7.198
			13	2	12.872
				7	9.568
				12	7.627
		1400	1	2	17.987
				7	13.885
				12	11.286
			7	2	19.741
				7	15.050
				12	12.166
			13	2	19.692
				7	16.012
				12	12.609
	3	200	1	2	3.686
				7	2.609
				12	2.120
			7	2	5.404
				7	3.573
				12	2.818
			13	2	5.590
				7	3.893
				12	2.977
		800	1	2	11.824
				7	9.425
				12	7.549
			7	2	13.542
				7	10.670
				12	8.334

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
8	3	800	13	2	14.078
				7	10.771
				12	8.633
		1400	1	2	20.430
				7	16.123
				12	13.166
			7	2	22.172
				7	17.167
				12	13.985
			13	2	22.829
				7	17.625
				12	14.065
	6	200	1	2	4.950
				7	3.430
				12	2.799
			7	2	7.268
				7	4.845
				12	3.630
			13	2	7.538
				7	5.466
				12	4.112
		800	1	2	16.107
				7	12.407
				12	9.886
			7	2	18.685
				7	13.549
				12	11.056
			13	2	18.626
				7	13.777
				12	11.407
		1400	1	2	27.295
				7	21.310
				12	17.628
			7	2	29.634
				7	22.396
				12	18.489
			13	2	30.038
				7	23.567
				12	19.241

Appendix CC. Guardrail Urban Local Coefficients

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	0	200	1	2	1.710
				7	1.198
				12	0.852
			7	2	2.428
				7	1.597
				12	1.173
			13	2	2.706
				7	1.865
				12	1.307
		800	1	2	5.196
				7	3.627
				12	2.520
			7	2	6.037
				7	4.394
				12	2.952
			13	2	6.349
				7	4.323
				12	3.241
		1400	1	2	8.655
				7	6.159
				12	4.555
			7	2	9.748
				7	6.900
				12	4.992
			13	2	10.071
				7	7.308
				12	5.172
	6	200	1	2	2.635
				7	1.892
				12	1.194
			7	2	3.832
				7	2.487
				12	1.700
			13	2	3.935
				7	2.794
				12	1.940
		800	1	2	7.755
				7	5.530
				12	3.884
			7	2	9.256
				7	6.569
				12	4.605

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
0	6	800	13	2	9.448
				7	6.897
				12	4.913
		1400	1	2	12.619
				7	9.807
				12	6.729
			7	2	14.518
				7	10.553
				12	7.310
			13	2	15.381
				7	10.892
				12	7.585
	12	200	1	2	2.308
				7	1.833
				12	1.164
			7	2	3.526
				7	2.488
				12	1.704
			13	2	4.163
				7	2.812
				12	1.906
		800	1	2	7.633
				7	6.151
				12	4.037
			7	2	8.698
				7	6.574
				12	4.439
			13	2	9.773
				7	6.843
				12	4.861
		1400	1	2	12.635
				7	9.613
				12	6.765
			7	2	14.226
				7	10.167
				12	7.241
			13	2	14.901
				7	11.110
				12	7.840
3	0	200	1	2	2.044
				7	1.354
				12	0.923

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	0	200	7	2	2.977
				7	1.900
				12	1.348
			13	2	3.220
				7	2.205
				12	1.472
		800	1	2	6.048
				7	4.412
				12	3.075
			7	2	6.775
				7	5.085
				12	3.454
			13	2	7.297
				7	5.203
				12	3.690
		1400	1	2	9.962
				7	7.363
				12	5.166
			7	2	11.125
				7	7.866
				12	5.571
			13	2	11.636
				7	8.292
				12	5.817
	6	200	1	2	2.913
				7	1.948
				12	1.393
			7	2	4.384
				7	2.930
				12	1.964
			13	2	5.103
				7	3.252
				12	2.137
		800	1	2	9.112
				7	6.463
				12	4.600
			7	2	10.734
				7	7.206
				12	5.067
			13	2	11.001
				7	7.822
				12	5.489

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
3	6	1400	1	2	14.908
				7	10.699
				12	7.684
			7	2	16.536
				7	12.080
				12	8.318
			13	2	17.227
				7	12.262
				12	8.721
	12	200	1	2	2.966
				7	2.027
				12	1.474
			7	2	4.426
				7	2.838
				12	1.983
			13	2	4.947
				7	3.280
				12	2.269
		800	1	2	9.170
				7	6.324
				12	4.645
			7	2	10.644
				7	7.463
				12	5.144
			13	2	10.988
				7	7.905
				12	5.451
		1400	1	2	15.244
				7	10.575
				12	7.538
			7	2	16.541
				7	12.134
				12	8.485
			13	2	16.568
				7	12.343
				12	8.797
6	0	200	1	2	8.084
				7	5.324
				12	3.653
			7	2	12.187
				7	7.958
				12	5.515

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	0	200	13	2	14.126
				7	9.273
				12	6.017
		800	1	2	23.178
				7	17.217
				12	11.769
			7	2	27.508
				7	20.136
				12	13.804
			13	2	29.140
				7	20.679
				12	14.893
		1400	1	2	39.534
				7	28.607
				12	21.077
			7	2	43.514
				7	32.411
				12	21.240
			13	2	45.276
				7	32.827
				12	24.292
	6	200	1	2	11.815
				7	7.888
				12	5.499
			7	2	18.025
				7	11.894
				12	8.028
			13	2	22.862
				7	14.078
				12	9.118
		800	1	2	35.184
				7	25.905
				12	17.978
			7	2	41.882
				7	29.324
				12	20.222
			13	2	43.923
				7	32.106
				12	22.015
		1400	1	2	61.302
				7	43.682
				12	30.032

Degree of Curvature	Grade (%)	Length of Feature (ft)	Height of Feature (ft)	Offset (ft)	b
6	6	1400	7	2	67.112
				7	48.816
				12	33.102
			13	2	68.321
				7	48.738
				12	34.856
	12	200	1	2	12.084
				7	8.184
				12	5.703
			7	2	18.242
				7	11.570
				12	7.938
			13	2	19.927
				7	13.815
				12	9.158
		800	1	2	34.823
				7	26.079
				12	18.012
			7	2	41.679
				7	30.406
				12	20.588
			13	2	44.988
				7	32.453
				12	21.333
		1400	1	2	61.592
				7	42.883
				12	30.146
			7	2	66.338
				7	47.063
				12	33.002
			13	2	70.262
				7	49.932
				12	34.353