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Abstract

The severity of a roadside feature is often based on survey responses and has tended to emphasize extreme crash events, thereby overestimating the average severity of a particular feature. In this study, severity was related to embankment geometry by examining real-world accident data over a 7-year period. This was done by correlating the number of severe and fatal accidents to the exposure of particular slope geometries. Slope geometry was described by slope steepness and fill height, and its exposure was described by traffic volume and total unshielded mileage. Severity was adjusted for posted speed limits as well. The Roadside Safety Analysis Program (RSAP) was calibrated such that the distribution of severe injury and fatal accidents accurately reflected real-world data. Using this calibrated version of RSAP, the new severity indexes were studied and equations were created to correlate severity index to functional class, fill height, slope steepness, and posted speed limit. The local highway classification provided the highest severity, and the default severity used in RSAP was increased to accommodate this finding. Freeways, rural arterials, and urban arterials experienced reduced severity indexes relative to default values used in RSAP.

Keywords: RSAP, roadside safety, benefit-cost analysis, severity index, foreslopes, embankments, roadside, severe accidents, fatal accidents

1. Introduction

1.1. Background

The proportion of embankment-related fatal crashes has increased since 1994. In 0.9% of the 6,492,000 accidents in 1994, an embankment was the first harmful event (FHE); however, embankments were the FHE in 2.7% of the 36,223 fatal accidents (National Highway Traffic Safety Administration, 1994). In 0.9% of the 5,505,000 accidents in 2009, an embankment was the FHE; however, embankments were the FHE in 3.3% of the 30,797 fatal accidents in 2009 (National Highway Traffic Safety Administration, 2009). Even though the total percentage of accidents on embankments has not changed, the proportion of fatal accidents has increased, prompting an investigation into the actual severity of embankments.

In contrast, the approach to modeling the severity of these geometric features has changed little since 1994. As a result, an approach was taken to correlate real-world accident data to the severity index (SI) of an embankment, which could then be used in a comprehensive benefit–cost analysis using a probability-based encroachment tool known as the Roadside Safety Analysis Program (RSAP). To do so, accident data was collected in the State of Ohio between 2000 and 2006. Only severe injury and fatal accidents were analyzed because the societal costs of these accidents were much greater than the moderate injury costs. One benefit to this approach is that the effect of under-reporting may be minimized. The combined total of severe and fatal accidents will be referred to hereafter as A+K accidents.

RSAP used user-specified segment lengths in its modeling process. Therefore, the RSAP-simulated number of A+K accidents was given per mile (or km) of roadway. As a result, an approach was taken to estimate the number of A+K accidents per unit length for each functional class, slope steepness, and embankment height. In addition, RSAP includes a set of default design features for use in modeling foreslopes. The steepness of the slope is permanently coupled with a fill height. These slopes are described by a vertical (V) to horizontal (H) ratio. Four different slopes were considered: (1) 1V:2H, (2) 1V:3H, (3) 1V:4H, and (4) 1V:6H. The two steepest slopes had a wide range of possible fill heights. For this research, fill heights were limited to 1-, 7-, and 13 ft (0.3, 2.1, and 4.0 m, respectively). For 1V:4H slopes, only two options were applicable: 1 ft (0.3 m) and ≥7 ft (2.1 m). The 1V:6H slope had only one option: ≥1 ft (0.3 m). Therefore, a total of nine slope-height combinations were generated.

Originally, five functional classes were considered, including freeways, rural arterials, urban arterials, rural local highways, and urban local highways. After the data was collected, it was decided to combine the rural and urban local highways due to insufficient sample size for the urban local highways.

1.2. Objectives

The objectives of this research were to (1) establish a methodology to estimate the SI for foreslopes based on real-world accident data and (2) calibrate the accident data results in RSAP for use in conducting accurate benefit–cost analyses on foreslopes.

1.3. Literature Review

Glennon and Tamburri (1967) may have been among the first researchers to begin studying what would become known as severity indexes. Glennon defined an SI as a numerical weighing scheme that ranks roadside obstacles by degree of accident consequence (Glennon, 1974). Together, they devised an equation to determine SI based on the number of fatal, injury, and property damage only (PDO) accidents (Glennon & Tamburri, 1967). It placed the heaviest weight on fatal accidents and no weight on PDO accidents. However, the weights used in this approach are no longer valid because a significant push has been made since then to remove deadly objects from the clear zone. It also allowed for SIs to be larger than ten, whereas, today's approach utilizes a scale of 0 to 10, with the latter representing a fatal accident in 100% of the accidents.

In the mid-1970s, Perchonok et al. (1978) used accident data from six states in an attempt to determine fixed-object severities. In this study, police officers were trained to collect additional data using a supplemental form. Perchonok et al. found that embankments had injury rates well above average. However, his study used data from lower functional classes such as rural arterials, where crash severities tend to be higher. In addition, seat belt usage in the mid-1970s was much less prevalent than it is today, which may also have influenced crash severities.

Weaver et al. (1975) established a scale similar to the one used today. Each severity index was defined by a percentage of fatal, injury, and PDO accidents as determined by survey responses. In these surveys, participants were asked to rank roadside objects by their severity. Then, accident reports were correlated with survey responses. They estimated a SI of 3.0 on roadside slopes that were built up of sod. No variation was correlated to slope steepness.

McFarland and Rollins (1985) set out to validate Weaver et al.'s (1975) research. To do so, they examined 136,000 accidents between 1978 and 1979 in Texas. Their results showed that Weaver et al.'s indexes were too high, and surveys were an unreliable source for determining severity indexes.

Brogan and Hall (1985) studied fixed objects in New Mexico between 1980 and 1982. They observed that a single SI was insufficient to describe any roadside feature. Instead, they concluded that the SI should be a function of exposure as well. By determining a severity scale for an object, researchers could use this scale and accident frequency to determine an annual accident cost, a method later adopted into RSAP.

Mak (1985) investigated the relative severity of objects based on the percentage of severe injury and fatal accidents. The number of A+K accidents at a location was divided by the number of A+K accidents at all locations. Therefore, this process yielded relative SI values, rather than a range or scale. However, no variation was correlated to slope steepness.

The 1996 American Association of State Highway Transportation Officials (AASHTO) *Roadside Design Guide* (*RDG*) contained injury level percentages for each SI on a scale of 0 to 10. These values appear to have been generated from engineering judgment rather than from an empirical process. However, it is these values that served as the spring board for the default values established in RSAP.

Wolford and Sicking (1997) established a correlation between impact speed and SI for varying steepnesses using accident data collected in Michigan between 1985 and 1991. They assumed representative slope steepnesses of 1V:4H, 1V:3.5H, and 1V:2.5H for rural interstates, rural arterials, and rural collectors, respectively. In addition, the SI was determined at a constant 6.6-ft (2.0-m) fill height, which was assumed to represent an average height for the analyzed locations.

In sum, all previous research which studied SIs is either outdated, addresses restricted classes of highways, provides no correlation between crash severity and varying slope steepness, and/or is based on unreliable engineering judgment only. The latest study, which attempted to link severity values to embankment geometry, did not use real slope steepness and height measurements. Therefore, accuracy in Wolford and Sicking's (1997) embankment geometry is unknown, in contrast with the present research, which measured in-site embankment geometries using computer-generated topographical maps. Therefore, there is a need to develop more recent and accurate SIs for a variety of embankment configurations and a more comprehensive highway class group.

1.4. Research Approach

Over 30 years, the process by which the severity of an object was determined has morphed dramatically. This research utilized the A+K approach first investigated by Mak (1985), but the SI values were based on a scale of 0 to 10 rather than on a relative severity. Similar to Wolford and Sicking (1997), real-world accident data was used to establish a SI on varying slopes. Unlike Wolford and Sicking, the results of this research are not limited to one representative slope and one representative fill height per functional class (for a total of three), but rather are applicable to nine slope-height combinations (four slopes and three heights) for each of the four functional classes (for a total of 36). Also, unlike previous research which attempted to link embankment crash severity to inaccurate embankment geometry, this study precisely determined embankment geometry.

To begin the research, the mileage of the highway network in Ohio was examined using Light Detection and Ranging (LiDAR) files to measure slope steepness and embankment height. Measurements were taken on 100-ft (30.5-m) increments over 150 random 1- mile (1.6-km) segments. These random locations were chosen by tabulating the roadway description inventory reports for the highway network in Ohio. By doing so, segments in the table were defined by various features, such as mileposts or intersections with other roads. A random number generator was used to select 150 of these segments. Then, an additional random number was used to select a starting milepost within that segment. Using these measurements, the estimated mileage of 1V:2H, 1V:3H, 1V:4H, and 1V:6H slopes was determined. After a preliminary analysis was completed on these results, it was found that the severity of the steeper slopes was unreasonably low. It was observed that a large percentage of the length of the steeper slopes would have been shielded with longitudinal barriers, per recommendations in the *RDG* (American Association of State Highway and Transportation Officials 2006). Thus, it became necessary to estimate the mileage of unshielded slopes.

From the measured locations previously described, random locations were selected where the slope was steeper than 1V:3.5H. These locations were found using Google Maps, and the presence or absence of longitudinal barriers was noted using the street view. This investigation was completed for two steepness categories: steeper than 1V:2.5H (representing 1V:2H slopes) and flatter than 1V:2.5H but steeper than 1V:3.5H (representing 1V:3H slopes). Based on the *RDG* recommendations for slope shielding, it was determined that adjustments were not needed for slopes that were 1V:4H or flatter. Once the percentage of unshielded slopes was known, the total mileage for each slope was adjusted to represent only unshielded slopes.

Before a final severity estimate could be made, the accident data itself was processed according to slope steepness, slope height, average daily traffic (ADT), posted speed limit (PSL), and functional class. The number of A+K accidents was normalized to a constant ADT and PSL and then annualized. This value was then divided by the estimated unshielded mileage for each of the slope steepnesses to determine the frequency of A+K accidents based on ADT and PSL. With this data, RSAP was calibrated by adjusting SI modification factors until the simulated A+K frequency matched the accident data.

2. Data Collection and Analysis

Data collection and analysis was conducted in three phases: (1) estimating total mileage of each slope steepness and fill height combination in Ohio, (2) estimating the proportion of unshielded slopes in Ohio, and (3) estimating the frequency of A+K accidents. For this study, the sample size included 816

A+K accidents. With this real-world accident data, RSAP was calibrated for future use in conducting benefit-cost analyses. In addition, SI model equations were developed as functions of functional class, slope steepness, embankment height, and speed limit.

2.1. Total Mileage

An inventory of State and U.S. highways in the State of Ohio was used to randomly select 150 segments throughout the highway network. Applicable roadway segments were conceptually abutted together. Segments were defined between major roadway features, such as city limits or intersections. Then, 150 locations were randomly selected across the conjoined highway network.

Once locations were selected, measurements of the slope steepness and embankment height were taken every 100 ft (30.5 m). It was assumed that the 50 ft (15.2 m) before and after the location was reflected in the measurement at the midpoint. Each segment was adjusted to account for the beginning and end locations, where measurements were only 50 ft (15.2 m) long. After completing the measurements for one segment, the total length was actually 5,300 ft (1,615.4 m).

Slope and height combinations were chosen based on default options in RSAP. For the 1V:2H and 1V:3H slopes, heights of 1 ft, 7 ft, and 13 ft (0.3 m, 2.1 m, and 4.0 m) were available. However, for 1V:4H slopes, only 1 ft and ≥7 ft (0.3 m and ≥2.1 m) were available. For 1V:6H slopes, only a height of ≥1 ft (0.3 m) was available. Therefore, the mileage proportion was developed according to these slopes and heights. Based on the 150 randomly selected segments in Ohio, the slope-height proportions were estimated and are shown in Table 1.

These proportions were applied to actual mileages recorded in Ohio by the Highway Safety Information System (HSIS) (Council & Mohamedshah, 2007). These mileages are given in Table 2. The total mileage for each slope-height combination and for each functional class can be determined by multiplying the length for the appropriate functional class (Table 2) by the proportions for the appropriate slope-height combination (Table 1).

Table 1. Estimated distribution for each slope-height combination given in percentage

| Slope | Fill Height, ft [m] | | |
	1 [0.3]	*7 [2.1]*	*13 [4.0]*
1V:2H	1.3%	1.0%	2.3%
1V:3H	1.9%	4.4%	1.7%
1V:4H	24.3%	10.2%	
1V:6H	54.8%		

Table 2. Mileages used for each functional class

Highway Class	Length, mi [km]	% of Total
Freeway	2,010 [3,235]	10.30
Rural arterial	4,886 [7,864]	25.03
Urban arterial	3,088 [4,959]	15.82
Rural local	8,972 [14,439]	45.96
Urban local	565 [909]	2.89

2.2. Mileage of Unshielded Slopes

Severity indexes were updated by normalizing the A+K accident frequency over 1-mile (1.61-km) lengths. This meant that if two slopes had the same number of A+K accidents but different lengths, the shorter segment would have a higher frequency, and by extension a higher severity, according to the methodology used in this research. However, using the values determined from Tables 1 and 2, the severity of the 1V:2H and 1V:3H slopes was less than the severity of the 1V:4H and 1V:6H slopes. This may be attributed to general shielding guidelines set forth in the *RDG*, which does not recommend the use of longitudinal barriers on slopes flatter than 1V:3H for any fill height (American Association of State Highway and Transportation Officials 2006). However, as fill height decreases, some of the steeper slopes no longer require shielding. As a result, an approximate proportion of unshielded slopes was determined using Google street views and the previously described random steep locations. They were classified as either 1V:2H (steeper than 1V:2.5H) or 1V:3H (between 1V:2.5H and 1V:3.5H). From the Google street view, the presence or absence of a barrier was recorded. A total of 110 locations were used for the 1V:2H slope, and 172 were used for the 1V:3H slope. On the 1V:2H slopes, the unshielded proportions for 1-, 7-, and 13-ft (0.3-, 2.1- and 4.0-m) fill heights were 71.43%, 37.50%, and 26.76%, respectively. The proportions on 1V:3H slopes for the same heights were 66.67%, 64.10%, and 64.62%, respectively. Statewide estimated mileages for each of the five functional classes shown in Table 2 were determined by applying the distributions shown in Table 1. After applying the adjustments, the total unshielded lengths were calculated, as shown in Table 3, using the unshielded proportions.

2.3. Traffic Volume Adjustment

Accidents in Ohio between 2000 and 2006 were recorded in the HSIS database and used in this analysis (Council & Mohamedshah, 2007). From this database, 816 severe or fatal accidents occurred and were selected for use in determining crash severity. The HSIS database contained traffic volume and posted speed limit data for each location. This data was described by eight ranges of ADTs for each functional class, which ranged from as little as 100

Table 3. Unshielded length of slopes on each functional class

Length of Unshielded Slopes, mi [km]		Fill Height, ft [m]		
		1 [0.3]	7 [2.1]	13 [4.0]
Freeway	1V:2H	18.92 [30.45]	7.40 [11.92]	12.15 [19.55]
	1V:3H	25.18 [40.52]	56.46 [90.86]	21.52 [34.63]
	1V:4H	487.74 [784.95]	204.09 [328.45]	
	1V:6H	1,100.49 [1,771.06]		
Rural arterial	1V:2H	45.99 [74.02]	18.00 [28.97]	29.53 [47.52]
	1V:3H	61.21 [98.51]	137.26 [220.89]	52.31 [84.18]
	1V:4H	1,185.81 [1,908.51]	496.19 [798.54]	
	1V:6H	2,675.52 [4,305.81]		
Urban arterial	1V:2H	29.06 [46.77]	11.38 [18.31]	18.66 [30.03]
	1V:3H	38.68 [62.25]	86.73 [139.58]	33.05 [53.20]
	1V:4H	749.32 [1,205.91]	313.54 [504.60]	
	1V:6H	1,690.67 [2,720.86]		
Rural local	1V:2H	84.45 [135.91]	33.06 [53.20]	54.22 [87.26]
	1V:3H	112.39 [180.87]	252.02 [405.59]	96.05 [154.57]
	1V:4H	2,177.28 [3,503.98]	911.06 [1,466.21]	
	1V:6H	4,912.54 [7,905.95]		
Urban local	1V:2H	5.32 [8.56]	2.08 [3.35]	3.41 [5.49]
	1V:3H	7.08 [11.39]	15.87 [25.54]	6.05 [9.73]
	1V:4H	137.11 [220.65]	57.37 [92.33]	
	1V:6H	309.35 [497.85]		

vehicles per day (vpd) on rural local highways to 155,000 vpd on freeways. Then, each accident was sorted into one of the nine slope-height categories and within the appropriate range of ADTs. The number of A+K accidents in each ADT range was normalized to 10,000 vpd by dividing the number of accidents by the median value of the range and multiplying by 10,000. The normalized number of A+K accidents was determined by summing the results over the traffic volume bins for each slope-height combination.

2.4. Posted Speed Limit Adjustment

Next, the PSL at the location of each accident was used to adjust accident frequency. In the current approach to SI determination, impact speed played a prominent role. From the HSIS database, freeways generally had PSLs above 55 mph. For PSLs less than 55 mph (88.5 km/h), RSAP relies on speed distributions for the specific functional class to determine the actual impact speed. Only when PSLs above 55 mph (88.5 km/h) are used would the results change, but these results are not supported by any real-world accident data (Mak & Sicking, 2002). However, rural local highways generally had PSLs less than 55 mph (88.5 km/h). Adjustment factors for each functional class were generated based on the number of accidents at each possible PSL, which ranged from 25 to 65 mph (40.3 to 104.7 km/h) in increments of 5 mph (8.1 km/h). At each PSL, the number of accidents was

Table 4. Posted speed limit adjustment factors for each functional class

Functional Class	Speed Limit Adjustment Ratio
Freeway	1.151
Divided rural arterial	1.109
Undivided rural arterial	0.982
Divided urban arterial	0.920
Undivided urban arterial	0.857
Rural local	0.971
Urban local	0.901

multiplied by the ratio of the PSL to 55 mph (88.5 km/h). The PSL adjustment factors are given in Table 4.

2.5. Accidents per Mile

The number of A+K accidents that were normalized by 10,000 vpd were summed for each slope-height combination and multiplied by the PSL adjustment ratios given in Table 4. This adjusted, normalized number of annual A+K accidents was then divided by the appropriate lengths from Table 3 to determine the frequency of A+K accidents as a function of ADT and PSL. Urban local highways, however, did not have enough severe injury or fatal accidents between 2000 and 2006 in Ohio to provide substantive data. Therefore, urban and rural local highways were combined for all further analyses. Additionally, the frequencies of divided and undivided highways were combined, but because adjustments for ADT and PSL had already been made, the effect of the adjustments was not lost. Expected crash frequencies for the four remaining functional classes are given in Table 5.

Table 5. Frequency of annual A+K accidents based on average daily traffic, posted speed limit, and 1-mile segments

	Fill Height, ft [m]					
	Freeway			Rural Arterial		
Slope	1 [0.3]	7 [2.1]	13 [4.0]	1 [0.3]	7 [2.1]	13 [4.0]
1V:2H	0.0018	0.0012	0.0073	0.0012	0.0245	0.0203
1V:3H	0.0000	0.0008	0.0013	0.0101	0.0068	0.0205
1V:4H	0.0000	0.0013		0.0021	0.0038	
1V:6H	0.0004	0.0026				
	Urban Arterial			Local		
Slope	1 [0.3]	7 [2.1]	13 [4.0]	1 [0.3]	7 [2.1]	13 [4.0]
1V:2H	0.0031	0.0043	0.0117	0.0803	0.2534	0.1070
1V:3H	0.0013	0.0003	0.0000	0.0448	0.0254	0.1291
1V:4H	0.0003	0.0007		0.0074	0.0132	
1V:6H	0.0007			0.0257		

2.6. Calibration of RSAP

A generic RSAP (v. 2003.04.01) model was created for the purpose of adjusting the SI of each slope-height combination on each functional class. Before an accurate calibration could be conducted, a coding error found within the structure of the user interface code for RSAP had to be fixed. RSAP models freeways as rural arterials, urban arterials as rural local highways, and rural local highways as freeways. The functional class code in the road.dat file was adjusted according to recommendations made in the *Cost-Effective Safety Treatments for Low-Volume Roads* (Schrum et al., 2012).

The ADT and PSL were set at a constant 10,000 vpd and 55 mph (88.5 km/h), respectively. The segment length and longitudinal length of the slopes were set at 1 mile (1.61 km). RSAP was intended to operate with annualized numbers. As a result, the simulated accident frequencies were in units of ADT-PSL-year-mile, which matched the adjusted normalized number of A+K accidents from Table 5. Each of the 36 possible slope-height-functional class combinations shown in Table 5 were modeled separately, and the SI modification factor found in RSAP (v. 2003.04.01) was adjusted until the simulated number of A+K accidents matched the real-world accident data. The resulting modification factors are shown in Table 6.

Table 6. Modification factors for severity index of foreslopes in the Roadside Safety Analysis Program

	Fill Height, ft [m]					
	Freeway			Rural Arterial		
Slope	1 [0.3]	7 [2.1]	13 [4.0]	1 [0.3]	7 [2.1]	13 [4.0]
1V:2H	0.38	0.26	0.33	0.40	0.55	0.48
1V:3H	0.37	0.33	0.34	0.75	0.53	0.67
1V:4H	0.46	0.47	0.66	0.64		
1V:6H	0.64			0.92		
	Urban Arterial			Local		
Slope	1 [0.3]	7 [2.1]	13 [4.0]	1 [0.3]	7 [2.1]	13 [4.0]
1V:2H	0.53	0.41	0.47	1.11	1.28	0.82
1V:3H	0.54	0.51	0.23	1.13	0.77	1.24
1V:4H	0.53	0.53		0.88	0.88	
1V:6H	0.79			1.56		

3. Results

Like most accident databases, it was possible that some severe injury or fatal accidents were miscoded according to the FHE. Researchers assumed that the available data represented a minimum number of accidents, and as a result, the concluding remarks with regard to SI represented minimum recommendations. It has been shown that police reporting may overestimate the number of severe accidents by as much as 49% (Farmer, 2003). If this holds true for this research, then the SIs may still be overestimated but are closer to real-world behavior than the default values used in RSAP.

From the results of the RSAP calibration, a generic set of equations was developed to relate SI to functional class, fill height, slope steepness, and PSL. To do so, the SI of each of the nine slope-height combinations was recorded. Based on the assumption of linearity between SI and speed made in the RSAP engineer's manual (Mak & Sicking, 2002), these SIs were used as the rise, whereas 55 was used as the run in a simple $y = mx + b$ equation, where the intercept was always zero.

To understand the effect of slope steepness, functional class, fill height, and PSL were controlled, and the steepness was varied. From this approach, equations were developed for each fill height and functional class (a total of 12 equations). Then, each equation was divided by 55 and multiplied by the PSL, which must be in terms of mph, resulting in the equations shown in Table 7. The only other variable, H, was the horizontal component of the slope steepness. For example, H equaled 2 for a 1V:2H slope.

Table 7. Minimum severity indexes of foreslopes in the Roadside Safety Analysis Program at 55 mph (88.5 km/h)

	Fill Height, ft [m]					
	Freeway			*Rural Arterial*		
Slope	*1 [0.3]*	*7 [2.1]*	*13 [4.0]*	*1 [0.3]*	*7 [2.1]*	*13 [4.0]*
1V:2H	1.48	1.47	1.94	2.34	2.39	2.44
1V:3H	1.36	1.42	1.61	1.88	1.90	1.99
1V:4H	1.30	1.39		1.65	1.65	
1V:6H	1.42			1.42		
	Urban Arterial			*Local*		
Slope	*1 [0.3]*	*7 [2.1]*	*13 [4.0]*	*1 [0.3]*	*7 [2.1]*	*13 [4.0]*
1V:2H	1.45	1.94	1.94	3.49	5.00	4.20
1V:3H	1.23	1.36	1.48	2.83	3.40	3.33
1V:4H	1.13	1.23		2.50	2.60	
1V:6H	1.02			2.17		

Table 8. Minimum severity index model equations

Functional Class	Drop Height, ft [m]	Severity Index Equations[a]
Freeway	1 [0.3]	$SI = \frac{1}{55} [\, 0.7166 \, (\frac{1}{H}) + 1.1186 \,] \times PSL$
	7 [2.1]	$SI = \frac{1}{55} [\, 0.3154 \, (\frac{1}{H}) + 1.3114 \,] \times PSL$
	13 [4.0]	$SI = \frac{1}{55} [\, 2.0126 \, (\frac{1}{H}) + 0.9386 \,] \times PSL$
Rural arterial	1 [0.3]	$SI = \frac{1}{55} [\, 2.7600 \, (\frac{1}{H}) + 0.9567 \,] \times PSL$
	7 [2.1]	$SI = \frac{1}{55} [\, 2.9451 \, (\frac{1}{H}) + 0.9171 \,] \times PSL$
	13 [4.0]	$SI = \frac{1}{55} [\, 2.6983 \, (\frac{1}{H}) + 1.0943 \,] \times PSL$
Urban arterial	1 [0.3]	$SI = \frac{1}{55} [\, 1.2720 \, (\frac{1}{H}) + 0.8100 \,] \times PSL$
	7 [2.1]	$SI = \frac{1}{55} [\, 1.5600 \, (\frac{1}{H}) + 0.8400 \,] \times PSL$
	13 [4.0]	$SI = \frac{1}{55} [\, 2.7369 \, (\frac{1}{H}) + 0.5704 \,] \times PSL$
Local	1 [0.3]	$SI = \frac{1}{55} [\, 3.9566 \, (\frac{1}{H}) + 1.5086 \,] \times PSL$
	7 [2.1]	$SI = \frac{1}{55} [\, 9.5966 \, (\frac{1}{H}) + 0.1986 \,] \times PSL$
	13 [4.0]	$SI = \frac{1}{55} [\, 5.2629 \, (\frac{1}{H}) + 1.5729 \,] \times PSL$

a. Posted speed limit (PSL) must be in mph. To convert km/h to mph, multiply PSL by 0.6214.

Severity indexes were a function of speed. At 0 mph (0 km/h), the SI would be zero for any scenario involving foreslopes flatter than a vertical drop. For the sake of demonstration, minimum SI values were generated at 55 mph (88.5 km/h) for each functional class, slope steepness, and fill height. The resulting severity indexes are shown in Table 8. Severity indexes were evaluated according to the equations in Table 7. For 1V:4H and 1V:6H fore-slopes, the SI was evaluated at the lowest fill height applicable to that slope. Each 1V:6H foreslope was evaluated at 1 ft (0.3 m), and each 1V:4H fores-lope was evaluated at 1 and 7 ft (0.3 and 2.1 m). where,

> SI = Severity index
> H = Horizontal component of the slope
> PSL = Posted speed limit.

3.1. Comparison of SI Values
RSAP (v. 2003.04.01) incorporated severity indexes published in the 1996 *RDG* (American Association of State Highway and Transportation Officials, 1996). The values in the *RDG* were based on surveys completed by highway safety officials and law enforcement officers. As a result, their evaluations of specific features were biased toward high-speed, severe crashes (Mak & Sicking, 2002), thus overestimating the SI. In Figure 1, default SI values from RSAP were compared with the adjusted SI values determined by this research for one slope-height combination, a 7-ft (2.1-m) tall, 1V:3H slope. For this particular slope-height combination, the default severity indexes used in RSAP were all higher than those found in this study.
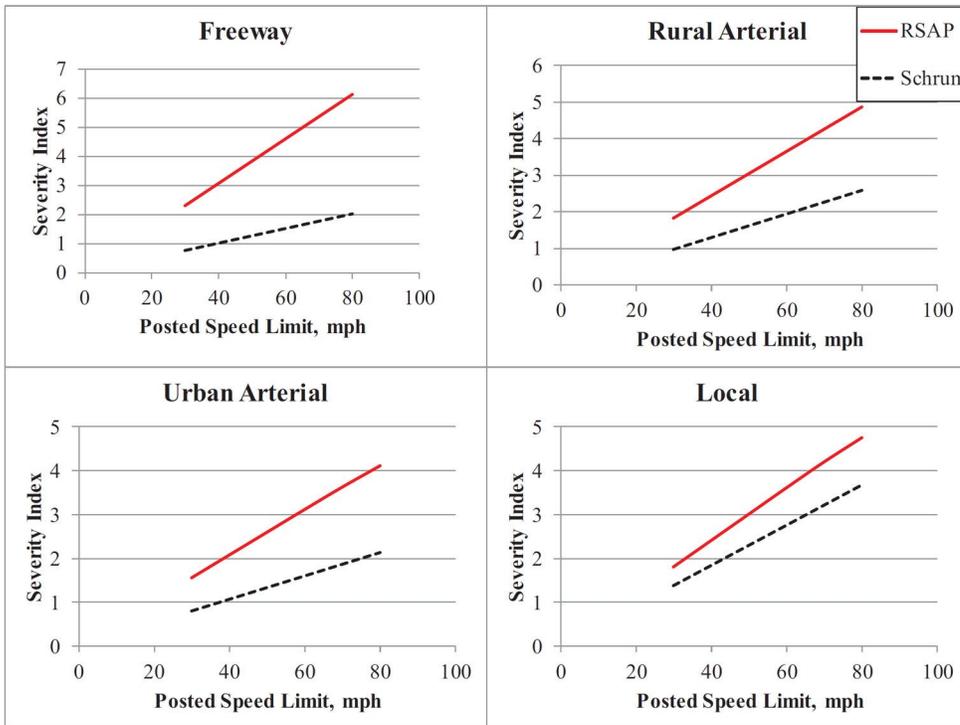
Fig. 1. Severity index comparisons on a 1V:3H slope for a 7-ft (2.1-m) fill height. RSAP = Roadside Safety Analysis Program.

Table 6 is a useful tool for comparing SI values. Those modification factors represented a percentage of the default RSAP SI value. For example, if the modification factor was 0.5 and the original SI was 10, then the new SI would be 5. If the modification factor was greater than 1.0, then the new value was higher than the default value. The results in Table 6 show that the SI increased only on the local highway classification. The maximum increase was 56%, as seen on the 1V:6H slope. The maximum decrease occurred on the freeway classification, where the SI was reduced by 74% on 1V:2H slopes for a 7-ft (2.1-m) fill height.

The default values in RSAP were overestimated due to human interpretation of the severity of roadside features. This research correlated real-world accident data to the steepness of the foreslope, thus eliminating error caused by human interpretation. As a result, the SI values presented in this study are more indicative of real-world scenarios.

4. Summary, Discussion, and Conclusion

Real-world accident data was collected over a 7-year period and used to correlate crash severity to embankment geometry. This was done by approximating the number of A+K accidents per mile for slope steepnesses

of 1V:2H, 1V:3H, 1V:4H, and 1V:6H and for fill heights of 1, 7, and 13 ft (0.3, 2.1, & 4.0 m), resulting in nine different embankment configurations. The total roadside slope mileage was determined by examining approximately 150 miles (241.5 km) of highway segments, which were representative of the Ohio State highway network. By using the proportion of each slope-height combination, the total mileage in the state was determined. This total mileage was adjusted for 1V:2H and 1V:3H slopes to account for un-shielded slopes. Finally, the data was normalized to 10,000 vpd and 55 mph (88.5 km/h), resulting in units of A+K accidents per 10,000 vpd per 55 mph (88.5 km/h) per year per mile (or kilometer). This information was used to calibrate RSAP for freeways, rural arterials, urban arterials, and local highways. Once the calibration was complete, equations were generated relating SI to functional class, fill height, slope steepness, and posted speed limit.

Results shown in Table 7 indicated that roadside slopes on local highways held the highest severity. In this table, the traffic volumes were each set at 10,000 vpd, giving each functional class equal exposure. The higher SI values on local roads indicated a higher propensity for unshielded, steep slopes. In general, local roads had relatively small ADTs, making safety treatment practices, such as installing longitudinal barriers or incorporating clear zone designs, less stringent. Therefore, at equal ADTs, a local highway should exhibit higher severity indexes than the other functional classes.

Roadside slopes on local highways demonstrated one other interesting characteristic. Fill heights of 7 ft (2.1 m) had the highest severity, not the 13-ft (4.0-m) fill height. One possible explanation for this was in the methodology employed to find SI. Real-world A+K accidents may have been more prevalent on these fill heights. As the height decreased, the number of serious accidents decreased because of a reduced risk caused by the slope. As the fill height increased, the number of serious accidents decreased because other safety treatment options, such as barriers, were employed.

In conclusion, default SI values for foreslopes in RSAP were modified to reflect real-world accident data. Severity indexes associated with roadside slopes were reduced on freeways, rural arterials, urban arterials and some slope-height combinations for local highways but were increased on other slope-height combinations for local highways. These severity indexes were believed to be indicative of the real-world accident data at this time. As time marches forward and design methodologies change, this process needs to be repeated to update crash severity based on current practices and accident data.

5. Recommendations

Recall that a benefit–cost analysis requires accurate assessments of the features being studied. Therefore, because current SI values are overestimated, the results of this analysis should be used in future embankment studies, until the accident data can be updated. Severity indexes should be determined

according to the equations in Table 7. If RSAP is being used to conduct a benefit–cost analysis on embankments, the data file used by RSAP to reference embankment severities should be modified according to recommendations shown in Table 6. Readers are referred to Schrum et al. (2011) for the entire list of accident costs generated for each highway scenario considered in the present study.

Additionally, RSAP has been updated recently and utilizes a different platform than RSAP v2, which is FORTRAN-based, Monte-Carlo simulation. RSAP v3, on the other hand, integrates Microsoft Excel with deterministic encroachment paths, wherein, once a collision is predicted, a series of tables are used to correlate the collision velocity and angle with a cost. Using the calibrated version 2 of RSAP, the newer version can be tested for accuracy on roadside slopes, and where needed, modified to match real-world accident data.

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