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FINAL REPORT

GUARDRAIL NEED FOR EMBANKMENTS AND CULVERTS

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16. Abstract

A cost-effectiveness analysis procedure was utilized to study safety treatment options for embankments and culverts on 3R projects. The study examined the need for cable and w-beam guardrail to shield traffic from roadside embankments and roadside culverts, respectively. Average embankment and culvert accident severities were estimated using Highway Safety Information System (HSIS) data from Utah and Michigan. Average accident severities were calibrated through computer simulations of ran-off-road accidents. Simplified design charts were developed to allow highway engineers to quickly determine the need for cable and w-beam guardrail on 3R projects.

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ABSTRACT

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CHAPTER 1. INTRODUCTION

American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA) guidelines state that safety improvements should be considered whenever resurfacing, rehabilitation, or restoration (3R) work is undertaken. Under this program, highway designers are required to consider safety improvement alternatives for most roadside hazards along each section of the highway to be rehabilitated. Unfortunately, there are currently no nationally recognized criteria for identifying the best safety treatment alternatives for roadside slopes and culverts. AASHTO's Roadside Design Guide does present a chart comparing the relative severities of roadside slopes and guardrails, as shown in Figure 1. However, this chart does not consider the benefits and costs of guardrail installation, merely which alternative would yield the lowest accident costs. This type of safety treatment guideline is not appropriate for low volume rural highways common in Nebraska and the Roadside Design Guide encourages highway agencies to use cost effectiveness techniques to develop warranting criteria for barrier protection of roadside slopes.

Although the Roadside Design Guide presents some safety treatment alternatives for roadside cross-drainage culverts, it does not offer any guidelines for safety treatment of these structures. Safety treatment options for roadside culverts include extending the culvert opening farther away from the travelway, and shielding the culvert with guardrail. However, no specific criteria are available for determining conditions under which any of these safety treatments should be implemented.

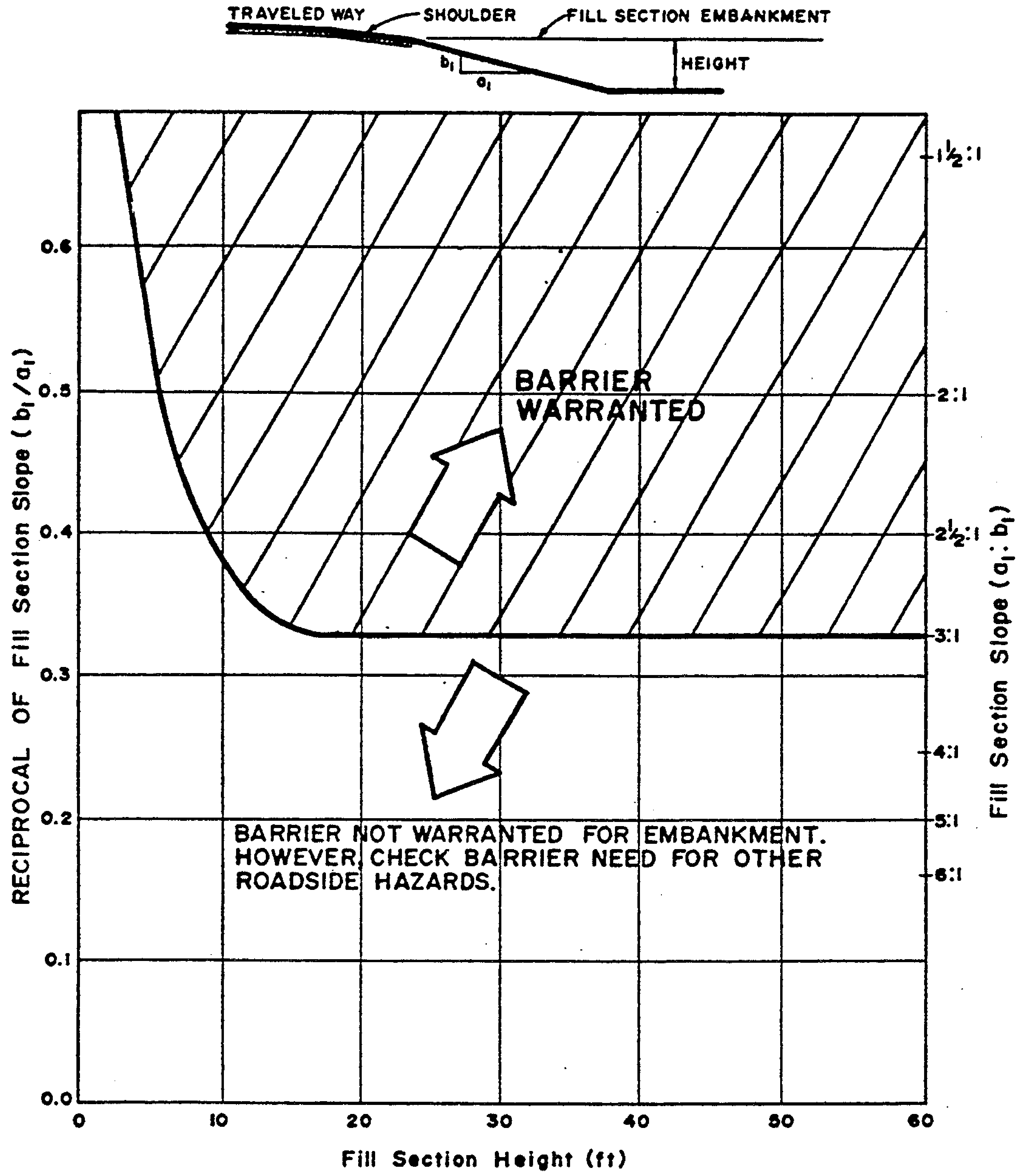

FIGURE 1. COMPARATIVE RISK WARRANTS FOR EMBANKMENTS.

Nebraska Department of Roads' (NDOR) design engineers follow the Minimum Design Standards set by the State Board of Public Roads Classifications and Standards for 3R projects. These standards have minimum requirements for fill slopes to be used in place and for fixed obstacle clearances. Due to the lack of general safety guidelines for treatment of roadside slopes and culverts, NDOR design engineers currently conduct benefit/cost analyses for those roadside slopes and cross drainage culverts which do not meet the minimum 3R standards and are located along highways slated for 3R projects. As recommended in the Roadside Design Guide, the NDOR uses the Roadside program for conducting these benefit/cost analyses. Unfortunately, the Roadside program is a relatively crude benefit/cost analysis model with a difficult user interface and questionable accuracy. As a result, the program is both time consuming to use and its findings are sometimes inappropriate.

A number of other, more sophisticated benefit/cost analysis programs are now available that are more accurate, including the Benefit to Cost Analysis Program (BCAP) (1) and the ABC model (2). The BCAP program was used by FHWA to develop AASHTO's Guide Specifications for Bridge Rails (3) and the ABC model was developed by the Texas Transportation Institute and used to develop safety treatment guidelines for a number of roadside safety problems (4,5). These programs provide more accurate estimates of the benefits and costs associated with safety treatment of roadside slopes and culverts than can be conducted with the Roadside program. Thus, objective warranting guidelines for the safety treatment of roadside slopes and culverts could be developed using these more accurate programs that would both greatly simplify the design procedure and provide more cost-effective 3R designs.

The objective of this report was to develop simplified guidelines for the safety treatment of roadside slopes and culverts.

CHAPTER 2. RESEARCH APPROACH

The research described in this report involved a two-phase approach to develop procedures for cable and w-beam guardrail warranting for roadside slopes and culverts. The first phase involved analysis of accident data to obtain average severities for embankments and culverts. The second phase consisted of a benefit/costs analysis of cable guardrail systems protecting a roadside slope and of w-beam guardrail systems protecting roadside slope or a culvert. Details of each of these procedures are described in the following two sections.

Accident Data Analysis

A literature review was conducted to identify any prior research into the benefit/cost analysis of roadside slopes and culverts. Since all benefit/cost analysis programs require some estimate of accident severity, the literature review focused on the identification of the best source of severity information for accidents involving roadside slopes and cross-drainage culverts. Several studies of the safety treatment of culverts and slopes have been conducted with varying degrees of success. One such study involved the analysis of accident data which required linking state accident data bases and roadside inventory files to develop accident frequency predictions (6,7). Although the researchers were not successful in developing accurate accident frequency predictions, it was thought that valuable severity information could be extracted from these accident files.

Therefore, state accident data files were obtained from the Highway Safety Information System (HSIS) at the Highway Safety Research Center at the University of North Carolina. These state police level accident databases are separated into several data files that can be linked together. Accident data from Michigan and Utah were obtained from HSIS. The accident data in

Michigan was collected from 1985 through 1991, while in Utah the data was collected from 1985 through 1992.

As stated above, the goal of this accident data analysis is to obtain the average accident severities of both roadside slopes and culverts. The severity of Police Level Accident data is usually defined in terms of injury probability to occupants of the impacting vehicle, using the police injury code and the KABCO severity scale, as shown in Table 1 (8). However, it was critical to the analysis to ensure that the accident data base being used was clean and relatively free of coding errors. Therefore, both the Michigan and Utah data bases were checked for consistency to verify the accuracy of the key data elements from year to year. When the consistency check was completed, the severities for all fixed object accidents were obtained and classified by both functional class and rural/urban designations. Further detail of the analysis of the accident data is presented in chapter 3.

TABLE 1. SUMMARY OF POLICE INJURY CODE (PIC)

PIC Level	Injury Description	Illustrative Examples
K	Fatal	
A	Incapacitating Injury	Unable to walk, drive, etc.
B	Non-incapacitating Injury	Bump on head, abrasions, minor lacerations
C	Possible Injury	Limping, complaint of pain
PDO	Non-Injury	Property damage only

Benefit/Cost Analysis

A benefit/cost analysis is frequently used to examine the relative merits of two safety treatment options. These techniques attempt to estimate the number and severity of roadside accidents associated with each safety treatment option. The benefits of a safety improvement are then compared to the direct highway agency costs associated with the improvement, where the benefits are measured in terms of reductions in accident costs. A safety improvement may be installed if the estimated benefits of a specific design exceed the cost of constructing and maintaining that design over a period of time. The research approach incorporated for this study involved evaluating increasing embankment widths until the benefits of installing an appropriately designed cable or w-beam guardrail outweigh the costs in consideration of the benefit/cost ratio. This also included the evaluation of shielding various culvert sizes with a w-beam guardrail, while increasing the lateral offset to the face of the culvert until the benefits of installing an appropriately designed w-beam guardrail became larger than the associated cost.

The severity of accidents predicted to occur are the most important component of any benefit/cost analysis. For evaluation of embankment warrants, the severity of an embankment accident along with the severity of a cable or w-beam guardrail accident are of primary importance. Average embankment severities obtained and adjusted for unreported accidents were supplemented through computer simulation to establish severities based on both embankment slope and width. Cable and w-beam guardrail severities were estimated by computer simulation of guardrail impacts. For evaluation of culvert warrants, the severity of a culvert accident and the severity of a w-beam guardrail accident are of primary importance. The average embankment severities obtained and adjusted for unreported accidents were supplemented through computer simulation and engineering judgement to establish severities based on culvert size.

CHAPTER 3. ACCIDENT DATA ANALYSIS

As described above, a literature review was conducted to identify any prior research containing severity information on roadside slopes and culverts. Although the data obtained and analyzed from the Highway Safety Information System (HSIS) formed much of the initial severity information used in this study, one other study, conducted by Perchonok (9), also provided some useful data and insight into the use of accident data. The following section will discuss Perchonok's study, which will be followed by a discussion of the accident data obtained from HSIS.

Perchonok Accident Data

The Perchonok study is based on accident data collected in six states: California, Georgia, Maine, South Dakota, Tennessee, and Wyoming. The accident data were collected by training the investigating police officers in each area to collect additional data, relevant to the study, using a supplemental form. These data were then extended with highway photolog data obtained from state highway departments. A total of 7,972 accidents were collected over a period ranging from 1975 to 1977, which varied by state. The data were only collected on rural, non-Interstate, highways with low traffic volumes, and consisted of only single-vehicle accidents. Undivided, two-lane highways contributed 85% of the data and the remainder of the data was collected on divided or separated roadways.

To obtain all of the desired accident data, Perchonok found that it was necessary that an intensive investigation of every applicable accident be conducted, not just the more severe accidents, as is often the practice. The definition of every applicable accident is one which the first injury or damage producing event occurred after at least one wheel exited the roadway or occurred as a result with direct contact with an obstacle immediately adjacent to the roadway. Data were collected over a wide variety of climatic regions and topographical types. Also, these data were collected where the road construction practices and traffic densities differ from state to state, and may not coincide with those in Nebraska.

A population is represented by the sample if the data are collected and analyzed in prescribed ways and the results are said to be characteristic of a larger domain. Hence, it is important to know from which population the data were collected, so that some conclusions on the generality of the results may be obtained. The data were clearly not collected in such a manner to provide nationwide generality (9).

Perchonok's fixed object severities are shown in Table 2. Overall, the results confirm that the most severe roadside objects are also the most rigid. The most dangerous hazards are the

TABLE 2. Perchonok's Severity by Fixed Object.

OBJECT STRUCK	SEVERITY			TOTAL	%(K)	%(K+I)
	Fatal	Nonfatal	None			
Bridge or overpass entrance	14	52	22	88	15.9%	75.0%
Tree	48	405	214	667	7.2%	67.9%
Field approach	1	49	25	75	1.3%	66.7%
Culvert	14	130	87	231	6.1%	62.3%
Embankment	18	216	172	406	4.4%	57.6%
Wooden utility pole	14	292	292	598	2.3%	51.2%
Bridge or overpass side-rail	2	40	40	82	2.4%	51.2%
Rocks(s)	1	35	37	73	1.4%	49.3%
Ditch	4	176	188	368	1.1%	48.9%
Ground	5	69	79	153	3.3%	48.4%
Trees and Brush	5	93	157	255	2.0%	38.4%
Guardrail	5	85	194	284	1.8%	31.7%
Fence	1	78	246	325	0.3%	24.3%
Small Sign Post	1	16	59	76	1.3%	22.4%
TOTAL	133	1736	1812	3681	3.6%	50.8%

bridge/overpass entrances, where 75 percent of the accidents resulted in either an injury or a fatality. Similarly trees, field approaches, culverts and embankments all had injury rates well above average. The highest fatality rates were observed for the following fixed objects, the culvert, a tree and the bridge or overpass entrance.

HSIS Gross Accident Data

The Highway Safety Information System (HSIS) contains many state accident data bases, two of which are Utah and Michigan. The Highway Safety Research Center at the University of North Carolina maintains the HSIS for the Federal Highway Administration. As previously stated, the HSIS contains Michigan data files for the period between 1985 through 1991, and the Utah data files cover the period from 1985 through 1992. Michigan accident data are discussed in the next section, and will be followed by a discussion of the Utah accident data.

Michigan Gross Accident Data

The Michigan accident data is separated into three accident subfiles, the accident subfile, the vehicle subfile and the occupant subfile. Other files available are the segment file, the trunkline vehicle mile file, the guardrail inventory file, the intersection file, and the electrical traffic control device inventory file (10). These files are available in Statistical Analysis System (SAS) format, and can be linked together (11). The files pertinent to the severities of roadside slopes and culverts are the accident subfiles and the segment file. The accident subfile contains basic information on accident type, location and environment, while the vehicle subfile contains information on each vehicle in the crash and each driver. The occupant subfile contains information on each occupant injured in each vehicle. The roadway segment file contains roadway information such as, shoulder, traffic volume, pavement type, functional class, etc.

The accident data in Michigan is coded by the Michigan State Police, and the accident report form is standardized throughout the state. The reporting threshold is either personal injury and/or a total estimated property damage of at least $250. Approximately 147,000 accidents occur per year in Michigan, where 70% are multi-vehicle accidents and 30% are single-vehicle (10). Considering all accidents, approximately 72.6% are property damage only accidents, 27% are injury accidents and .4% are fatal accidents (10).

In a study by Kihlberg and Tharpe (12), the report notes that multi-vehicle accident rates increase with traffic volume, and that single-vehicle accident rates decrease with increasing traffic volume. It is also noted that the multi-vehicle accident rate occurs in significant numbers near intersections, and that the severity rates are generally not affected by geometric features of the roadway. The effect of access control is substantial. Partial access control produces measurable improvement, while full access control cuts accident rates by as much as two-thirds.

In light of the preceding paragraph, the Michigan accident data used in this analysis to obtain severities by fixed object were limited to single-vehicle accidents, with no intersections or interchanges, and all missing and errant values were removed. The fixed object accident severity for all roadways is shown in Table 3. Again, as expected, the results confirm that the most severe roadside objects are also the most rigid. The culvert accident is one of the most severe roadside hazards. In fact, Table 3 shows that impacts with culverts, although infrequent, result in the highest percentage of people sustaining a combination of a fatality and a serious injury. Embankment accidents, however, are not the most severe, but they are one of the most frequent accidents that occur. In comparison to the Perchonok severities, the Michigan data are significantly less severe, especially with regards to recorded fatalities. One possible explanation is that the Perchonok data represent lower functional classes where severities are typically higher. Also, in 1976 when Perchonok's data were being collected, seat belt usage was less prevalent than it is today. Perchonok's data was collected and investigated by specially trained police officers. In such studies, it is often the practice to investigate the most severe accidents. Even though Perchonok realized this and attempted to remedy this problem, he may not have been entirely successful.

TABLE 3. MICHIGAN 1985-1991: ALL ROADWAYS
Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	SEVERITY								
	FATAL	INJURY LEVEL			PDO				
	K	A	B	C	O	TOTAL	%(K)	%(K+A)	%(K+I)
No object hit	614	4516	1686	7323	115950	130089	0.5%	3.9%	10.9%
Guardrail or guard post	66	642	311	1833	9552	12404	0.5%	5.7%	23.0%
Highway Sign	38	228	95	515	4675	5551	0.7%	4.8%	15.8%
Street light, Utility Pole	42	386	140	606	2861	4035	1.0%	10.6%	29.1%
Culvert	11	130	34	116	341	632	1.7%	22.3%	46.0%
Ditch, Embankment, Stream	30	844	427	2169	10340	13810	0.2%	6.3%	25.1%
Bridge Pier or Abutment	10	46	16	108	411	591	1.7%	9.5%	30.5%
Bridge rail or deck	7	26	12	121	515	681	1.0%	4.8%	24.4%
Tree	135	845	302	1119	4039	6440	2.1%	15.2%	37.3%
Highway or railroad signal	3	11	0	9	62	85	3.5%	16.5%	27.1%
Building	3	46	15	59	303	426	0.7%	11.5%	28.9%
Mailbox	15	169	73	346	3403	4006	0.4%	4.6%	15.1%
Fence	16	118	35	246	1488	1903	0.8%	7.0%	21.8%
Traffic island or curb	6	40	19	137	1281	1483	0.4%	3.1%	13.6%
Concrete median barrier	19	632	326	1792	5569	8338	0.2%	7.8%	33.2%
Other on-trafficway object	29	225	73	458	7128	7913	0.4%	3.2%	9.9%
Other-off-trafficway object	14	131	62	267	2541	3015	0.5%	4.8%	15.7%
Overhead fixed object	2	7	0	13	310	332	0.6%	2.7%	6.6%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	379	1059	149	628	201	2416	15.7%	59.5%	91.7%
TOTAL	1439	10101	3775	17865	170970	204150	0.7%	5.7%	16.3%

The fixed object that the vehicle hit denotes the first object the vehicle struck in a collision sequence. This is the only variable of this type; thus it is believed that it is probably a good indicator of the object that causes the most severe injuries. However, there actually is no variable that specifically represents the most harmful event. The Michigan data base severity was originally coded into three levels: a fatality, an injury, and a property damage only accident. Therefore, it was necessary to separate injury into three levels. The first level is the A injury, the second level is the B injury and the third is the C injury. This was accomplished by noting if there was an occupant with an A injury. If so, then the accident was denoted an A-injury accident, even if other occupants had other injuries that were less severe. Also this severity is accident based, not occupant based. A description of the police injury code (8) and a description with illustrative examples is shown in Table 1.

The fixed object accident severities for rural and urban roadways are shown in Tables 4 and 5 respectively. Again, as expected, the results confirm that the most severe roadside objects are also the most rigid. Culvert and embankment accidents are both more frequent and severe for rural roadways than for urban roadways. The frequency of rural accidents greatly out numbers the frequency of urban accidents; however, this is to be expected due to the much greater number of rural vehicle miles.

TABLE 4. MICHIGAN 1985-1991: RURAL ROADWAYS

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	SEVERITY								
	FATAL	INJURY LEVEL			PDO				
	K	A	B	C	O	TOTAL	%(K)	%(K+A)	%(K+I)
No object hit	308	2665	1085	4585	101217	109860	0.3%	2.7%	7.9%
Guardrail or guard post	38	299	196	782	4379	5694	0.7%	5.9%	23.1%
Highway Sign	14	124	50	279	2461	2928	0.5%	4.7%	15.9%
Street light, Utility Pole	16	167	55	246	1664	2148	0.7%	8.5%	22.5%
Culvert	10	100	30	92	234	466	2.1%	23.6%	49.8%
Ditch, Embankment, Stream	21	609	309	1417	6479	8835	0.2%	7.1%	26.7%
Bridge Pier or Abutment	3	17	6	33	155	214	1.4%	9.3%	27.6%
Bridge rail or deck	2	14	8	52	228	304	0.7%	5.3%	25.0%
Tree	94	628	227	812	2975	4736	2.0%	15.2%	37.2%
Highway or railroad signal	1	4	0	7	26	38	2.6%	13.2%	31.6%
Building	2	25	7	27	136	197	1.0%	13.7%	31.0%
Mailbox	12	132	58	247	2409	2858	0.4%	5.0%	15.7%
Fence	9	68	20	139	791	1027	0.9%	7.5%	23.0%
Traffic island or curb	3	9	5	16	233	266	1.1%	4.5%	12.4%
Concrete median barrier	0	27	28	118	579	752	0.0%	3.6%	23.0%
Other on-trafficway object	18	99	27	193	3152	3489	0.5%	3.4%	9.7%
Other-off-trafficway object	10	67	23	119	1493	1712	0.6%	4.5%	12.8%
Overhead fixed object	0	2	0	5	142	149	0.0%	1.3%	4.7%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	165	458	52	228	94	997	16.5%	62.5%	90.6%
TOTAL	726	5514	2186	9397	128847	146670	0.5%	4.3%	12.2%

The Michigan embankment severities classified by functional class are shown in Table 6. This table shows that significantly more embankment accidents occur on rural roadways, and are more severe than embankment accidents occurring on urban roadways. It appears that the embankment severities in Michigan increase with decreasing functional classification. Roadways with higher functional classification generally have flatter embankment slopes. Also, it seems that the frequency of accidents are lower for roadways with higher functional classification. Since higher functional classifications have a higher degree of access control, Kihlberg and Tharpe's results on access control reducing accident rates is correct. The Michigan fixed object accident severities classified by functional class are contained in Appendix A.

TABLE 5. MICHIGAN 1985-1991: URBAN ROADWAYS

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	SEVERITY								
	FATAL	INJURY LEVEL			PDO				
	K	A	B	C	O	TOTAL	%(K)	%(K+A)	%(K+I)
No object hit	306	1851	601	2738	14733	20229	1.5%	10.7%	27.2%
Guardrail or guard post	28	343	115	1051	5173	6710	0.4%	5.5%	22.9%
Highway Sign	24	104	45	236	2214	2623	0.9%	4.9%	15.6%
Street light, Utility Pole	26	219	85	360	1197	1887	1.4%	13.0%	36.6%
Culvert	1	30	4	24	107	166	0.6%	18.7%	35.5%
Ditch, Embankment, Stream	9	235	118	752	3861	4975	0.2%	4.9%	22.4%
Bridge Pier or Abutment	7	29	10	75	256	377	1.9%	9.5%	32.1%
Bridge rail or deck	5	12	4	69	287	377	1.3%	4.5%	23.9%
Tree	41	217	75	307	1064	1704	2.4%	15.1%	37.6%
Highway or railroad signal	2	7	0	2	36	47	4.3%	19.1%	23.4%
Building	1	21	8	32	167	229	0.4%	9.6%	27.1%
Mailbox	3	37	15	99	994	1148	0.3%	3.5%	13.4%
Fence	7	50	15	107	697	876	0.8%	6.5%	20.4%
Traffic island or curb	3	31	14	121	1048	1217	0.2%	2.8%	13.9%
Concrete median barrier	19	605	298	1674	4990	7586	0.3%	8.2%	34.2%
Other on-trafficway object	11	126	46	265	3976	4424	0.2%	3.1%	10.1%
Other-off-trafficway object	4	64	39	148	1048	1303	0.3%	5.2%	19.6%
Overhead fixed object	2	5	0	8	168	183	1.1%	3.8%	8.2%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	214	601	97	400	107	1419	15.1%	57.4%	92.5%
TOTAL	713	4587	1589	8468	42123	57480	1.2%	9.2%	26.7%

TABLE 6. MICHIGAN 1985-1991 EMBANKMENT SEVERITY BY FUNCTIONAL CLASSIFICATION

FUNCTIONAL CLASSIFICATION	FATAL	A	B	C	PDO	TOTAL
RURAL- PRIMARY ARTERIAL-INTERSTATE	5	90	38	206	1425	1764
RURAL- PRIMARY ARTERIAL-OTHER	9	174	90	468	2128	2869
RURAL-MINOR ARTERIAL	6	246	114	653	2476	3495
RURAL-MAJOR COLLECTOR	1	99	67	90	450	707
SUBTOTAL	21	609	309	1417	6479	**8835**
URBAN-PRIMARY ARTERIAL-INTERSTATE	1	89	33	272	1460	1855
URBAN-PRIMARY ARTERIAL-OTHER/FREEWAY	1	44	20	140	663	868
URBAN PRIMARY ARTERIAL OTHERS	7	97	63	320	1652	2139
URBAN-MINOR ARTERIAL	0	4	2	16	74	96
URBAN-COLLECTOR	0	1	0	4	12	17
SUBTOTAL	9	235	118	752	3861	**4975**
TOTAL	**30**	**844**	**427**	**2169**	**10340**	**13810**

The Michigan culvert severities classified by functional class are shown in Table 7. Similar to the embankment accidents, significantly more culvert accidents occur on rural roadways, and are more severe than embankment accidents occurring on urban roadways. However, there is no apparent correlation between culvert severity and functional class on rural roadways. Though, the culvert severity does increase slightly with decreasing functional class. Again, the effect of access control is apparent with lower accident frequencies occurring on roadways with a higher functional class.

TABLE 7. MICHIGAN 1985-1991 CULVERT SEVERITY BY FUNCTIONAL CLASSIFICATION

FUNCTIONAL CLASSIFICATION	FATAL	A	B	C	PDO	TOTAL
RURAL- PRIMARY ARTERIAL-INTERSTATE	1	5	1	8	27	**42**
RURAL- PRIMARY ARTERIAL-OTHER	4	33	9	38	67	**151**
RURAL-MINOR ARTERIAL	4	59	17	43	129	**252**
RURAL-MAJOR COLLECTOR	1	3	3	3	11	**21**
SUBTOTAL	10	100	30	92	234	**466**
URBAN-PRIMARY ARTERIAL-INTERSTATE	0	7	2	5	30	**44**
URBAN-PRIMARY ARTERIAL-OTHER/FREEWAY	0	4	0	4	14	**22**
URBAN PRIMARY ARTERIAL OTHERS	1	17	2	13	58	**91**
URBAN-MINOR ARTERIAL	0	2	0	2	4	**8**
URBAN-COLLECTOR	0	0	0	0	1	**1**
SUBTOTAL	1	30	4	24	107	**166**
TOTAL	**11**	**130**	**34**	**116**	**341**	**632**

Utah Gross Accident Data

The Utah accident data is separated into three accident subfiles, the accident subfile, the vehicle subfile and the occupant subfile. Other Utah files available are the roads file, the horizontal curve file, the vertical grade file, the railroad grade crossing file, the bridge file, and the materials file. The Utah data is available in SAS (11) format. Each file can be linked or combined with the other files; however, linking the Utah files was more difficult than linking the Michigan files. The Utah accident files relevant to the severities of roadside slopes and culverts are the accident subfiles and the roads file. Basic information on the accident type, location and environment are contained in the accident subfile. The vehicle subfile contains information on every vehicle involved in the crash along with information on each driver, while the occupant subfile includes both information on each occupant in each vehicle and non-occupants such as pedestrians or pedacyclists. The roads file has roadway information such as, shoulder, traffic volume, pavement type, pavement width, and functional class, etc.

Utah accident data is coded and edited by the staff at the Utah DOT based on the reports of the investigating officers. Approximately 48,500 accidents occur every year in Utah involving 80,500 vehicles and 116,000 occupants or pedestrians. The Utah data is unique in that it contains information on every occupant, not only those injured. Based on the complete data files, approximately 73% of the accidents are multi-vehicular in nature with the remaining 27% involving single-vehicles (13). Considering the complete data set, an estimated 71% are property damage only crashes, 28.4% are injury accidents, and .6% involve one or more fatalities(13).

The Utah accident data used in this analysis to obtain severities by fixed object were limited to single-vehicle accidents with ran-off-the-road accidents only. Further, all missing and errant values were removed from the analysis. This included an unknown functional classification, which was coded as “15" in the 1985 Utah roads file. The fixed object severity for all roadways is shown in Table 8. The embankment and bridge/culvert accidents are some of the most severe accidents occurring on Utah roadways. Utah bridge/culvert accidents are quite similar in severity values to those obtained from Michigan. However, there was some concern of the bridge/culvert variable and to what the bridge actually represented. In a phone conversation with Dave Blake, the main HSIS contact person at the Utah Department of Transportation (DOT), he stated that the bridge/culvert is only a culvert that sometimes functions similarly to a small bridge.

TABLE 8. UTAH 1985-1992: ALL ROADWAYS

Single-vehicle, Run-off-the-Road Accidents only, Remove missing and errant values

OBJECT STRUCK	SEVERITY								
	FATAL	INJURY LEVEL			PDO				
	K	A	B	C	O	TOTAL	%(K)	%(K+A)	%(K+I)
Guardrail	38	371	386	318	2089	3202	1.2%	12.8%	34.8%
Guardrail End	4	24	18	14	76	136	2.9%	20.6%	44.1%
Utility Pole	32	505	521	395	2290	3743	0.9%	14.3%	38.8%
Sign Post	27	189	181	139	1495	2031	1.3%	10.6%	26.4%
Delineator Post	99	592	427	273	1745	3136	3.2%	22.0%	44.4%
Bridge/Culvert	20	213	182	135	805	1355	1.5%	17.2%	40.6%
Curb	11	133	116	92	684	1036	1.1%	13.9%	34.0%
Safety Island	1	29	37	33	130	230	0.4%	13.0%	43.5%
Fence	56	497	467	353	2955	4328	1.3%	12.8%	31.7%
Rigid Concrete Barrier	15	241	254	220	1253	1983	0.8%	12.9%	36.8%
Crash Cushion	0	14	9	10	69	102	0.0%	13.7%	32.4%
Embankment	114	1043	943	571	2553	5224	2.2%	22.1%	51.1%
Wild Animal	0	2	7	4	24	37	0.0%	5.4%	35.1%
Domestic Animal	0	3	2	2	6	13	0.0%	23.1%	53.8%
Snow Bank	1	23	28	30	166	248	0.4%	9.7%	33.1%
Mailbox	2	31	33	30	288	384	0.5%	8.6%	25.0%
Channelizer	2	14	13	10	100	139	1.4%	11.5%	28.1%
Tree/Shrub	28	325	299	174	1054	1880	1.5%	18.8%	43.9%
Building	3	80	87	43	644	857	0.4%	9.7%	24.9%
Other Object	23	175	177	114	1138	1627	1.4%	12.2%	30.1%
TOTAL	476	4504	4187	2960	19564	31691	1.5%	15.7%	38.3%

Therefore, it is both Mr. Blake's and this researcher's opinion that the use of this variable to obtain estimates of average culvert accident severities is acceptable. The embankment accidents in Utah are significantly more severe than those in Michigan. That is because Utah contains many roadways in mountainous areas.

The Utah embankment severity information was not used in the development of embankment severities for this project, since it is believed that this information is not representative of the roadside conditions present in Nebraska.

The fixed object accident severities for rural and urban roadways are presented in Tables 9 and 10 respectively. Almost every fixed object severity appears to be more severe for rural roadways. In particular, both the bridge/culvert and embankment accidents are more severe on rural roadways. It is unusual, however, that the average accident frequencies on rural Utah roadways is nearly equal to those on urban Utah roadways. The severity of the delineator post is also somewhat peculiar in that it is so severe. This may be attributed to the method the original variables were coded. More specifically, the variable object struck represents the first event in the accident, not necessarily the most hazardous event. Although the Utah data did contain additional information regarding several subsequent events, this information represented the type of accident and not the fixed object struck. Therefore, a more in depth analysis to determine the most hazardous event occurring in a single accident was not possible with respect to fixed objects. Since, delineator posts typically denote hazards nearby, it is assumed that the delineator severity is due to a nearby unidentified hazard and not necessarily the delineator itself.

TABLE 9. UTAH 1985-1992: RURAL ROADWAYS

Single-vehicle, Run-off-the-Road Accidents only, Remove missing and errant values

OBJECT STRUCK	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
	FATAL	INJURY LEVEL			PDO				
	K	A	B	C	O				
Guardrail	24	180	188	111	926	1429	1.7%	14.3%	35.2%
Guardrail End	4	10	9	4	34	61	6.6%	23.0%	44.3%
Utility Pole	10	93	109	74	561	847	1.2%	12.2%	33.8%
Sign Post	21	88	82	54	534	779	2.7%	14.0%	31.5%
Delineator Post	83	485	325	195	1219	2307	3.6%	24.6%	47.2%
Bridge/Culvert	13	96	84	52	291	536	2.4%	20.3%	45.7%
Curb	1	11	14	8	52	86	1.2%	14.0%	39.5%
Safety Island	0	1	5	6	19	31	0.0%	3.2%	38.7%
Fence	45	317	276	174	1311	2123	2.1%	17.1%	38.2%
Rigid Concrete Barrier	8	76	74	58	363	579	1.4%	14.5%	37.3%
Crash Cushion	0	2	1	1	15	19	0.0%	10.5%	21.1%
Embankment	106	881	735	426	1960	4108	2.6%	24.0%	52.3%
Wild Animal	0	2	6	3	20	31	0.0%	6.5%	35.5%
Domestic Animal	0	3	2	2	5	12	0.0%	25.0%	58.3%
Snow Bank	1	16	17	25	129	188	0.5%	9.0%	31.4%
Mailbox	1	13	11	11	68	104	1.0%	13.5%	34.6%
Channelizer	1	8	4	2	27	42	2.4%	21.4%	35.7%
Tree/Shrub	20	153	146	85	493	897	2.2%	19.3%	45.0%
Building	0	15	27	8	268	318	0.0%	4.7%	15.7%
Other Object	17	70	66	38	401	592	2.9%	14.7%	32.3%
TOTAL	355	2520	2181	1337	8696	15089	2.4%	19.1%	42.4%

TABLE 10. UTAH 1985-1992: URBAN ROADWAYS

Single-vehicle, Run-off-the-Road Accidents only, Remove missing and errant values

OBJECT STRUCK	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
	FATAL	INJURY LEVEL			PDO				
	K	A	B	C	O				
Guardrail	14	191	198	207	1163	1773	0.8%	11.6%	34.4%
Guardrail End	0	14	9	10	42	75	0.0%	18.7%	44.0%
Utility Pole	22	412	412	321	1729	2896	0.8%	15.0%	40.3%
Sign Post	6	101	99	85	961	1252	0.5%	8.5%	23.2%
Delineator Post	16	107	102	78	526	829	1.9%	14.8%	36.6%
Bridge/Culvert	7	117	98	83	514	819	0.9%	15.1%	37.2%
Curb	10	122	102	84	632	950	1.1%	13.9%	33.5%
Safety Island	1	28	32	27	111	199	0.5%	14.6%	44.2%
Fence	11	180	191	179	1644	2205	0.5%	8.7%	25.4%
Rigid Concrete Barrier	7	165	180	162	890	1404	0.5%	12.3%	36.6%
Crash Cushion	0	12	8	9	54	83	0.0%	14.5%	34.9%
Embankment	8	162	208	145	593	1116	0.7%	15.2%	46.9%
Wild Animal	0	0	1	1	4	6	0.0%	0.0%	33.3%
Domestic Animal	0	0	0	0	1	1	0.0%	0.0%	0.0%
Snow Bank	0	7	11	5	37	60	0.0%	11.7%	38.3%
Mailbox	1	18	22	19	220	280	0.4%	6.8%	21.4%
Channelizer	1	6	9	8	73	97	1.0%	7.2%	24.7%
Tree/Shrub	8	172	153	89	561	983	0.8%	18.3%	42.9%
Building	3	65	60	35	376	539	0.6%	12.6%	30.2%
Other Object	6	105	111	76	737	1035	0.6%	10.7%	28.8%
TOTAL	121	1984	2006	1623	10868	16602	0.7%	12.7%	34.5%

The Utah embankment severities classified by functional class are presented in Table 11. As expected, accidents are both more frequent and more severe on rural roadways. In contrast to the Michigan embankment severities, the Utah embankment severities appear to decrease with decreasing functional class. Since construction of roadways through mountainous regions require a larger monetary investment per mile than roadways constructed on flat terrain and that more money is generally funded toward roadways with a higher functional classification, it is reasonable to assume that embankments on roadways with higher functional classes are located in mountainous regions. Therefore, determination of any correlation between functional class and accident frequency is complicated by terrain effects. The Utah accident severities classified by functional class for all fixed objects are contained in Appendix B.

TABLE 11. UTAH 1985-1992 EMBANKMENT SEVERITY BY FUNCTIONAL CLASSIFICATION

FUNCTIONAL CLASSIFICATION	FATAL	A	B	C	PDO	TOTAL
RURAL INTERSTATE	32	200	133	84	352	**801**
RURAL PRIMARY ARTERIAL	18	134	126	82	307	**667**
RURAL MINOR ARTERIAL	29	225	202	99	519	**1074**
RURAL MAJOR COLLECTOR	18	191	165	99	468	**941**
RURAL MINOR COLLECTOR	8	110	89	51	247	**505**
RURAL LOCAL	1	21	20	11	67	**120**
SUBTOTAL	106	881	735	426	1960	**4108**
URBAN INTERSTATE	0	47	58	51	113	**269**
URBAN FREEWAY	0	2	4	1	6	**13**
URBAN PRIMARY ARTERIAL OTHERS	3	24	37	31	94	**189**
URBAN MINOR ARTERIAL	4	30	41	24	171	**270**
URBAN COLLECTOR	0	28	35	15	119	**197**
URBAN LOCAL	1	31	33	23	90	**178**
SUBTOTAL	8	162	208	145	593	**1116**
TOTAL	**114**	**1043**	**943**	**571**	**2553**	**5224**

The Utah bridge/culvert severities categorized by functional class are shown in Table 12. In contrast to the Utah embankment severities, more accidents occur on urban roadways than on rural roadways. Nonetheless, the bridge/culvert severities on rural roadways are much more severe than those on urban roadways. Moreover, there is no clear indication that the severity of culvert accidents are related to functional classification. As with the Utah embankment data, it does not appear that the level of access control varies with lower bridge/culvert accident rates, as shown by the interstate accident rates.

TABLE 12. UTAH 1985-1992 BRIDGE/CULVERT SEVERITY BY FUNCTIONAL CLASSIFICATION

FUNCTIONAL CLASSIFICATION	FATAL	A	B	C	PDO	TOTAL
RURAL INTERSTATE	2	40	32	18	119	**211**
RURAL PRIMARY ARTERIAL	3	18	12	8	49	**90**
RURAL MINOR ARTERIAL	2	17	10	8	34	**71**
RURAL MAJOR COLLECTOR	4	13	21	12	44	**94**
RURAL MINOR COLLECTOR	1	4	8	4	22	**39**
RURAL LOCAL	1	4	1	2	23	**31**
SUBTOTAL	13	96	84	52	291	**536**
URBAN INTERSTATE	2	49	46	47	286	**430**
URBAN FREEWAY	0	7	2	5	19	**33**
URBAN PRIMARY ARTERIAL OTHERS	1	11	12	5	33	**62**
URBAN MINOR ARTERIAL	1	23	22	13	80	**139**
URBAN COLLECTOR	2	15	11	10	44	**82**
URBAN LOCAL	1	12	5	3	52	**73**
SUBTOTAL	7	117	98	83	514	**819**
TOTAL	**20**	**213**	**182**	**135**	**805**	**1355**

CHAPTER 4. BENEFIT/COST ANALYSIS

The main objective of a benefit/cost analysis procedure is normally to provide a method for prioritizing funding choices. Determining where protection of embankments or culverts is warranted is an essential funding choice. Highway agencies should warrant sufficient guardrail installation to provide a reasonable level of protection for motorist running off the road but not so much that funds are expended unnecessarily and the number of injuries and fatalities associated with roadside accidents actually begin to increase. The embankment warranting analysis involved the evaluation of increasing embankment widths until the benefits of installing an appropriately designed cable or w-beam guardrail outweigh the costs. The culvert warranting analysis involved the evaluation increasing the lateral offset to the face of the culvert until the benefits of installing an appropriately designed w-beam guardrail outweigh the costs.

Encroachment probability based, benefit/cost models are the best tool for study warranting criteria for specific roadside features with specific roadside safety hardware at any particular site. These procedures attempt to relate the rate that vehicles run off the road to roadside accident rates through a probabilistic model (1,2,5). Encroachment rates developed from studies by either Hutchinson and Kennedy (14) or Cooper (15) are generally used in these techniques. Accident rates are then estimated based on the assumption that errant vehicles generally follow a straight path until the vehicle is stopped or brought under control. This assumption leads to a hazard envelope, shown in Figure 2, within which vehicles encroaching at a given angle will impact a roadside hazard unless stopped or brought under control. Distributions of encroachment speeds, angles, distances, and vehicle types are incorporated into the analysis to estimate the frequency and nature of each type of roadside accident.

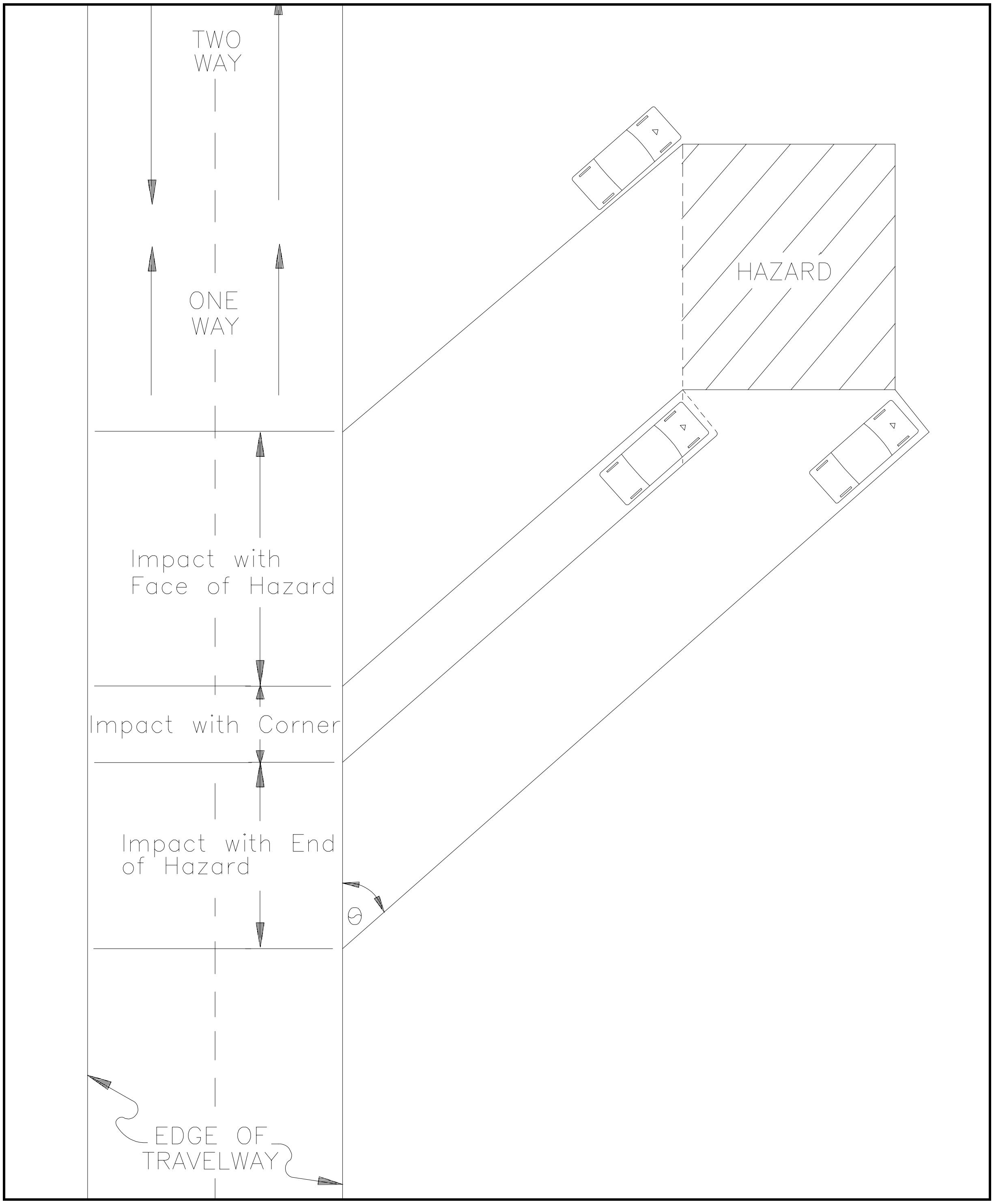

FIGURE 2. HAZARD ENVELOPE.

An advantage of some benefit/cost analysis programs is the ability to predict the number of accidents prevented from traveling behind the upstream section of a barrier. Another advantage of some benefit/cost analysis programs is the ability to predict the number of vehicles that penetrate the barrier, thus allowing a possible impact with the shielded hazard. As shown in Figure 3, a hazard imaging technique can be employed to estimate the risk associated with

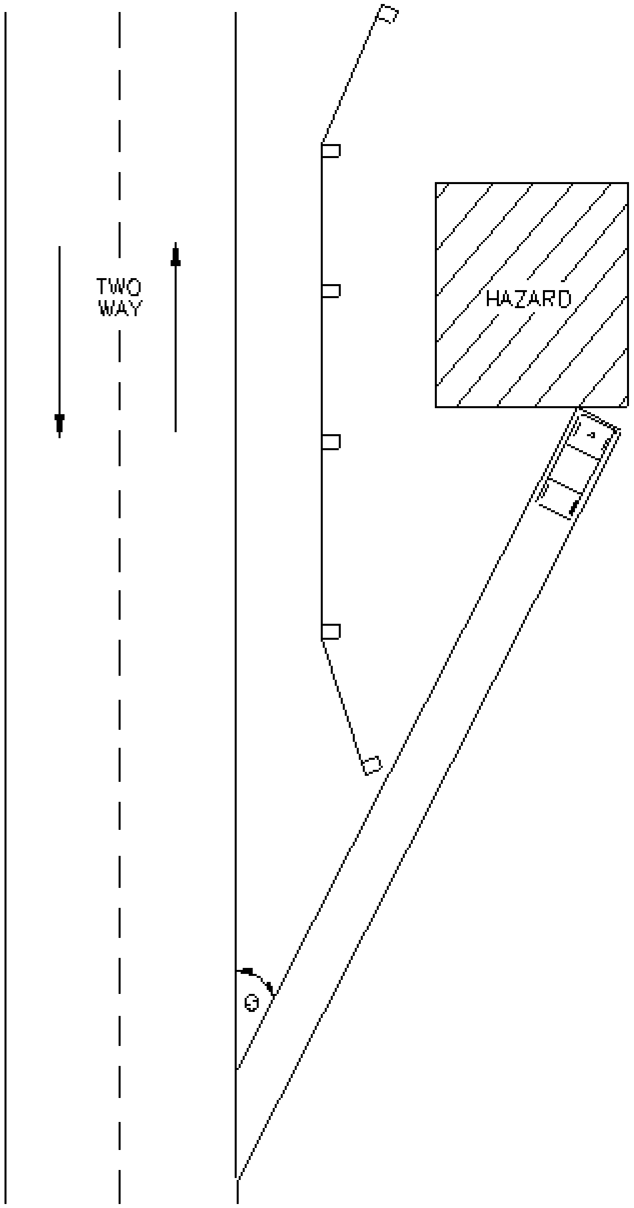

FIGURE 3. HAZARD IMAGING TECHNIQUE.

vehicles running behind the barrier to impact a roadside hazard. Only two procedures have been fully developed to date that incorporate such hazard imaging techniques, BCAP (1) and ABC (2). Although these two benefit-cost models are two different computer codes that evolved from the same original model, the programs are very similar. The researchers selected ABC for the current study because they are more familiar with this program and the input routines are generally better suited to studying the current problem. The following section presents a brief discussion of the benefit-cost analysis mode, much of which is excerpted from a paper by Sicking and Ross (2). This is followed by a presentation of severities used in the analysis, which is followed by a presentation of a set of warranting design charts for roadside slopes and culverts that are based on results developed with ABC.

Benefit-Cost Methodology

ABC is a computerized approach that compares the benefits derived from a safety improvement to the direct highway agency costs incurred as a result of the improvement. Benefits are measured as reductions in societal costs due to decreases in the number and/or severity of accidents. Direct highway agency costs comprise initial, maintenance, and accident repair costs associated with a proposed improvement. The ratio between the benefits and costs of an improvement, called the B/C ratio, is used to determine if a safety improvement is cost beneficial:

$$BC_{2-1} = \frac{SC_1 - SC_2}{DC_2 - DC_1} \tag{1}$$

where:

BC_{2-1} = Benefit/Cost ratio of alternative 2 compared to alternative 1.
SC_i = Societal accident costs associated with alternative i.
DC_i = Direct costs associated with alternative i.

In this approach, alternative 2 is initially assumed to be an improvement relative to alternative 1. If the benefit-cost ratio is less than 1.0, the predicted benefits are less than the predicted costs. Hence, the improvement is not justifiable and it should not normally be implemented. If the benefit-cost ratio for a safety improvement is greater than 1.0, the expected benefits are believed to be equal to or greater than the expected costs. So, the safety improvement is justifiable. Although budgetary limitations generally preclude funding of all projects that have a benefit-cost ratio of 1.0 or more, the benefit-cost ratio can still be used as a guide to prioritize safety improvements. After discussions with the design engineers at NDOR, a benefit-cost ratio of 2.0 was chosen to evaluate all safety improvement alternatives.

Factors that must be taken into account in the formulation of the benefit-cost analysis include the following: encroachment characteristics, accident costs, hardware installation costs, and repair costs. Details of the assumptions inherent in the general formulation of the benefit-cost analysis are presented elsewhere (2) and are not fully restated in this report. Details of the assumptions that are both specific to this study and required for proper interpretation of the results are discussed below.

Uncontrolled encroachment characteristics required for use in the benefit-cost methodology include frequency, speed, angle, and lateral movement. There are relatively few sources of such data available. The largest database available, which contains pure encroachment information, was collected on Canadian highways by Cooper (15). The Cooper study involved highways with operating speeds in the same range as those on most U.S. highways today. Therefore, the Cooper data were used to develop the necessary encroachment model. These data are available elsewhere and are not reproduced in this report (2,15).

As implemented in the ABC benefit/cost methodology, development of a relationship between encroachment characteristics (both angle and speed) and societal cost is a two step process. First a relationship between the impact speed, the impact angle and severity index must be established. This process involves estimating the likelihood of vehicle occupants being killed or injured during an impact at a given speed and angle. A variety of techniques, including full-scale crash testing, computer simulation, and accident data analysis, have been used to develop these relationships.

Cable Guardrail Severities

Full-scale crash testing and computer simulations of vehicular impacts generated surrogate measures of occupant risk, such as, maximum accelerations and estimated speeds at which occupants strike the vehicle interior. Unfortunately, very few studies have attempted to link these measures of occupant risk to probability of injury. The most successful of these efforts involved comparing vehicle damage during crash testing to vehicle damage arising from bridge rail accidents (16). Correlations between the Traffic Accident Damage (TAD) scales for these vehicles were then used to develop a relationship between maximum 50 millisecond average accelerations and the probability of injury as shown in Figure 4. Probabilities of injury can then be correlated with severity index by combining distributions of all injury and fatal accident probabilities for the severity index scale as shown in Table 13 (17). In this manner, severity of impact with cable guardrails was estimated for full-size automobiles using computer simulations and full-scale crash test results. As shown in Figure 5, the resulting cable guardrail severities for large automobiles seemed reasonable. This finding should not be surprising because of the type of vehicles associated with the development of the relationship between vehicle accelerations and probability of injury. During the 1960's and early 1970's, the vast majority of vehicles sold in the

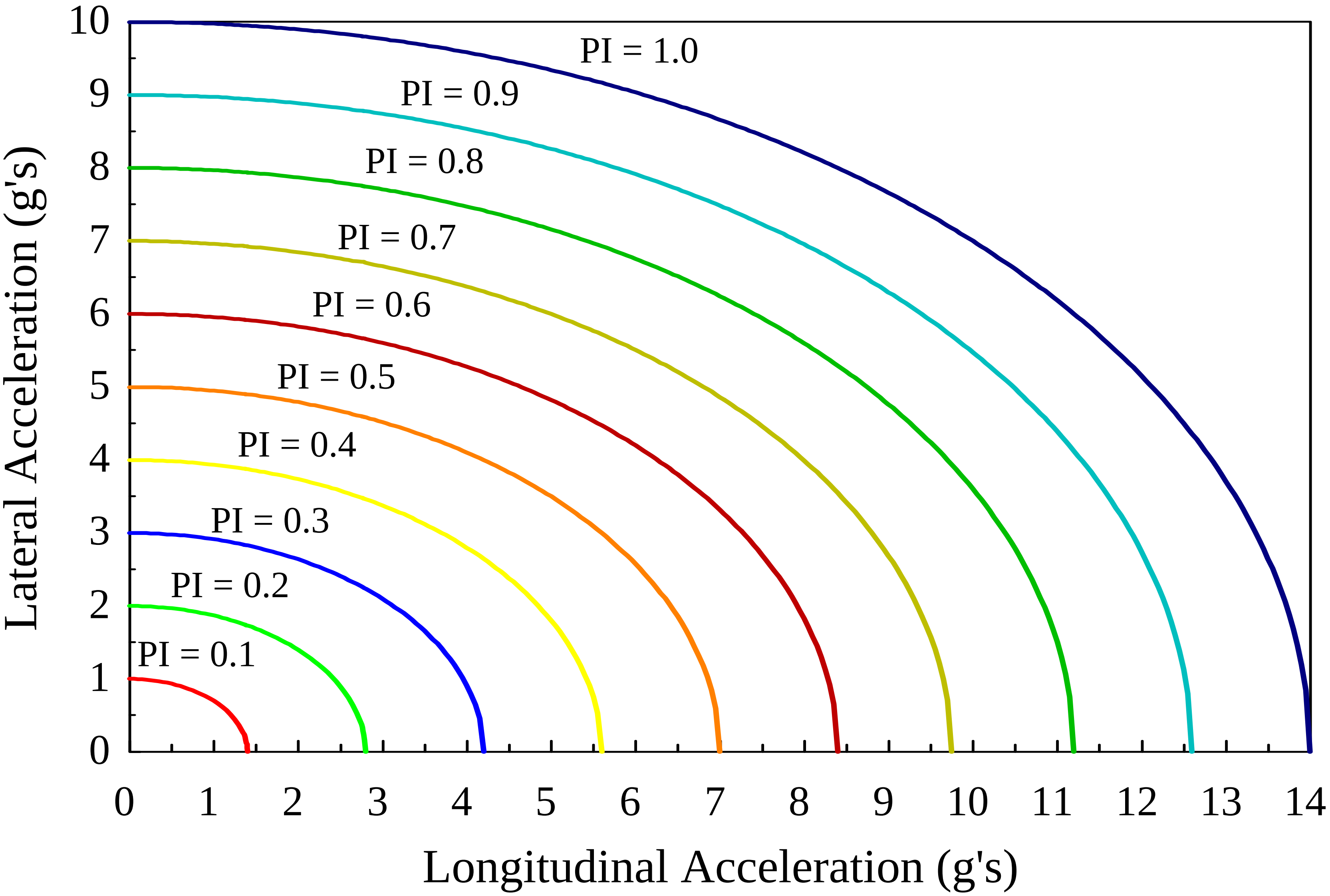

FIGURE 4. PROBABILITY OF INJURY ELLIPSE.

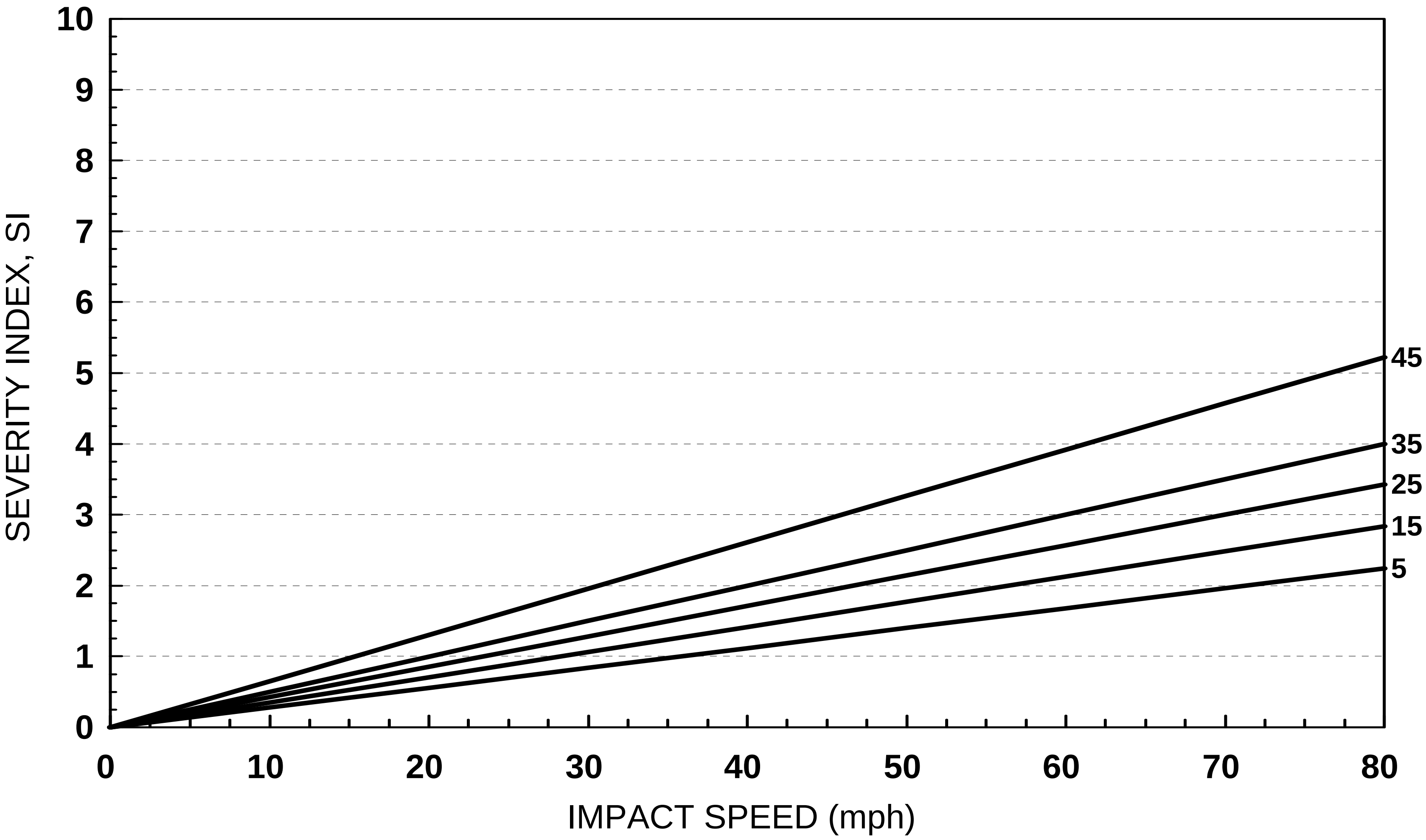

FIGURE 5. SEVERITY OF CABLE GUARDRAIL.

U.S. were in the full-size category. Therefore, most of the vehicles involved in the development of Figure 4 were in this category. Since this procedure may not be valid for use with small automobiles, Figure 5 was used for all automobile cable guardrail impact severities.

Accident Costs/Accident Data Check on Cable Guardrail Severity

Once the relationships between encroachment characteristics and the severity index are established, a relationship between the severity index and societal costs is needed to evaluate societal costs. After careful consideration of the appropriate societal costs for use with roadside safety analysis, relationships found in the 1995 update of the AASHTO Roadside Design Guide (18) were incorporated into the study. This relationship between the severity index and societal costs, is presented in Table 13. As shown in this table, the cost of a fatal accident, an accident with a severity index of 10, is set at $1,000,000.

The severity of the cable guardrail impact shown in Figure 5 was then compared with accident data as another check of its validity. First, accident data for cable guardrails were obtained from a report (19) that studied the Longitudinal Barrier Special Studies (LBSS) accident file. Table 14 shows the gross cable guardrail accident severities obtained from the LBSS file (19). Note there are not very many observations recorded, and that no fatalities or A-injuries occurred. Consequently, it is believed that this data slightly under estimates the severity of cable guardrail accidents. Perhaps if more data were available, both fatal and A-injury accidents would be recorded. Since these data do not include unreported accidents, a direct comparison of the accident prediction model of the ABC benefit/cost analysis program is inappropriate. To make such a comparison, the effects of unreported accidents on gross accident severities must be estimated.

TABLE 13. SEVERITY INDEX AND COST BY ACCIDENT TYPE DISTRIBUTION.

Severity Index	Property Damage (1)	Property Damage (2)	Slight Injury	Moderate Injury	Severe Injury	Fatal Injury	Total	Probability of Injury	Accident Cost ($)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
0.5	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0	625
1.0	66.7	23.7	7.3	2.3	0.0	0.0	100.0	9.6	1,719
2.0	0.0	71.0	22.0	7.0	0.0	0.0	100.0	29	3,919
3.0	0.0	43.0	34.0	21.0	1.0	1.0	100.0	57	17,244
4.0	0.0	30.0	30.0	32.0	5.0	3.0	100.0	70	46,063
5.0	0.0	15.0	22.0	45.0	10.0	8.0	100.0	85	106,919
6.0	0.0	7.0	16.0	39.0	20.0	18.0	100.0	93	225,694
7.0	0.0	2.0	10.0	28.0	30.0	30.0	100.0	98	363,938
8.0	0.0	0.0	4.0	19.0	27.0	50.0	100.0	100	556,525
9.0	0.0	0.0	0.0	7.0	18.0	75.0	100.0	100	786,875
10.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100	1,000,000

TABLE 14. LBSS CABLE GUARDRAIL CHECK

Police Injury Code (PIC)		Accident Costs	Reported Accidents		Adjusted Accidents		Benefit/Cost Analysis Percent
Injury Description	Injury Level		Gross LBSS	Percent LBSS	Adjusted LBSS	Percent LBSS	
Fatal Accident	Fatal	$1,000,000	0	0.0%	0	0.00%	0.21%
Severe Injury	A	$200,000	0	0.0%	0	0.00%	0.21%
Moderate Injury	B	$12,500	10	18.9%	15	15.57%	3.43%
Slight Injury	C	$3,750	8	15.1%	24	24.91%	9.11%
Property Damage Only	PDO	$1,500	35	66.0%	57	59.53%	87.04%
TOTAL			53	100.0%	96	100.00%	100.00%
1995 Roadside Design Guide Costs						$3,252	$4,483

Researchers have attempted to estimate the magnitude of the unreported accident problem by comparing reported accident frequency with the rate that marks appear on longitudinal barriers (20) or barrier repair frequencies (21). An 8:1 ratio between unreported and reported accidents is indicated from studies of marks on longitudinal barriers such as W-beam guardrail. Marks on roadside barriers can be caused by something other than traffic accidents. Therefore, it is believed that this ratio is somewhat high. For example, items that become dislodged from vehicles and fall into the roadway are often knocked off the travelway and impact a roadside barrier with sufficient force to cause detectable damage or marks. Further, crash testing and accident investigations show that vehicles often impact a roadside barrier twice during a single impact event because of damage to vehicle suspensions. Thus, two or more distinct and separate areas of damage often result from a single impact.

Efforts to compare cable barrier repair frequencies with reported accident rates indicate a ratio in the range of 1:1.6 between unreported and reported accidents (21). Although these studies involved cable barriers that should require repairs even for relatively minor impacts, some portion of the low speed, low angle accidents would be expected to require no repair. Thus, this procedure probably underestimates the magnitude of the unreported accident problem.

Considering the above discussion, it can be concluded that between 38 and 89 percent of longitudinal barrier accidents go unreported. For purposes of comparing reported accident severities with encroachment probability model predictions, it was assumed that approximately 45% of the cable guardrail impacts go unreported. The gross cable guardrail accident data were then adjusted for unreported accidents based on the assumption that no severe injury or fatal accidents would go unreported. Of the unreported accidents it was assumed that 12% were moderate injury accidents, while 37% were minor injury accidents, as shown in Table 14. Average accident costs were estimated based on accident costs for fatal, injury, and PDO accidents published in the 1995 Roadside Design Guide (18) and shown in Table 14.

Using severity index and impact angle relationships shown in Figure 5, the ABC model was then run to determine predicted severity levels and average accident costs. As shown in Table 14, the predicted average accident costs are not too different from the adjusted accident data findings. Although the accident distributions are somewhat dissimilar, it is believed that the problem rests with the accident data and the limited number of observations obtained and not with the cable guardrail severities developed using computer simulation. Even though the accident severities used in this analysis cannot be completely validated due to problems with both the accident data obtained and unreported accidents, the cable guardrail impact severities used in Figure 5 appear to correlate reasonablely well with available accident data.

All cable guardrail installations require a cable guardrail terminal. Therefore, some estimates of severity, installation cost and repair cost need to be made. In brief, the average accident severity chosen to represent the cable guardrail terminal was obtained from the 1996 Roadside Design Guide (18). To account for the concrete end block, the installation cost was assumed to be $365.00 per unit.

W-Beam Guardrail Severities

Initially, cable guardrail was selected for shielding culverts. It was later realized that the use of cable guardrail to shield culverts was inappropriate due to problems with maximum dynamic deflection. Therefore, w-beam guardrail was selected for protection of culverts. Severities, installation costs and repair costs for w-beam guardrail were developed under previous research (24) and will not be discussed further. Again, all guardrail installations require a terminal. Therefore, the Slotted Rail Terminal (SRT-100) was selected as the terminal for strong post w-beam guardrail. The average accident severity chosen to represent the SRT-100 guardrail was obtained from the 1996 Roadside Design Guide (18). The installation cost was estimated to be approximately $1250.00 per unit.

Direct Costs

Direct costs associated with cable guardrail use include installation, repair, and maintenance costs of the barrier. For the analysis presented in this report, the initial installation costs of cable guardrails were obtained from bid summaries obtained from NDOR engineers. The average installation cost for cable-guardrail was approximately $4.46 per linear foot. The ABC benefit/cost analysis program requires that the repair cost be entered as a slope representing the repair cost per ft-lb of energy due to an impact with a vehicle. This relationship between impact severity (IS) and the repair cost is shown in Figure 6. In this relationship the impact severity is given as a function of a vehicle speed and angle of impact as follows:

$$IS = \frac{1}{2} m (V \sin\theta)^2 \tag{2}$$

where:

IS = impact severity,
m = mass of the vehicle,
V = speed of the vehicle, and
θ = impact angle (16).

Using crash test information, such as vehicle mass, impact speed, impact angle, and length of rail damaged combined with an itemized cost per linear foot and per post, it is possible to estimate the repair cost per length of rail damaged. A repair cost in dollars per impact energy can then be approximated by using the impact severity equation, the length of rail damaged, and the cost per length of rail damaged. Although the mobilization cost to repair the guardrail was taken into account, the estimated repair cost is believed to be lower than an actual repair cost if an accident occurred. However, this repair cost is therefore a conservative estimate, erring on the side of warranting a cable guardrail installation.

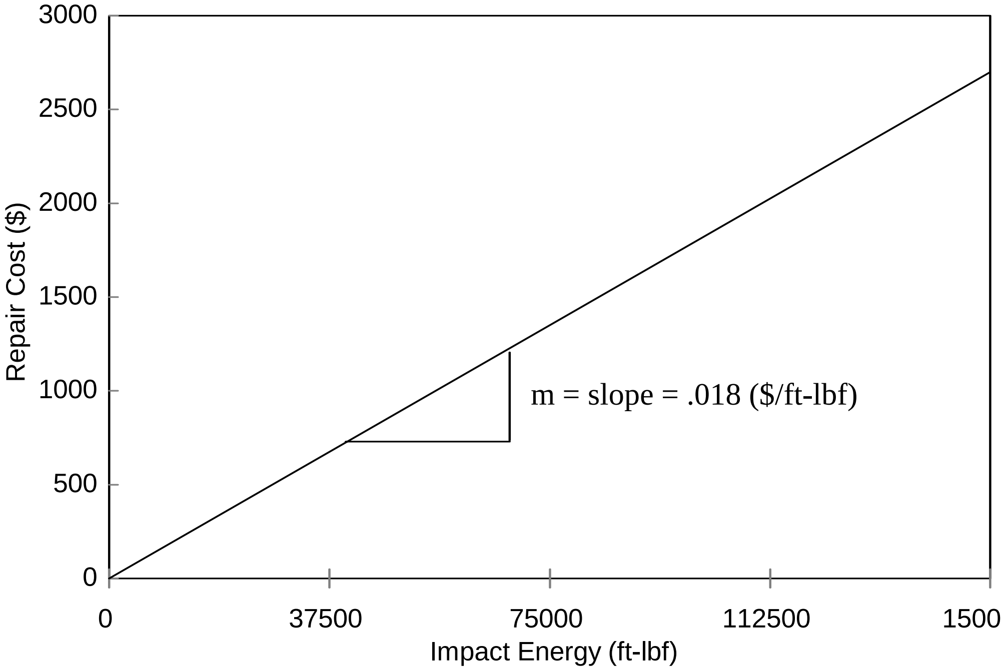

FIGURE 6. REPAIR COST RELATIONSHIP

Not all vehicles impacting cable guardrails are successfully redirected. In some cases the errant vehicle goes through or over the barrier. To accurately evaluate accident costs associated with such barrier impacts, a benefit-cost analysis must include a provision for guardrail penetration. The impact severity, as calculated in Equation 2, has been shown to be a reasonably good predictor of the propensity for a vehicle to penetrate through or over a longitudinal barrier (22). For purposes of this benefit-cost analysis, the capacity of cable guardrail was estimated to be 90,000 ft-lb for small automobiles and 150,000 ft-lb for full-size automobiles and trucks. However, theses cable guardrail penetration thresholds are believed to be somewhat high. The effect of using high penetration thresholds is to introduce conservatism into the process. If fewer vehicles are predicted to penetrate the barrier, the accident costs associated with the barrier are reduced and the benefit-cost ratio associated with barrier installation will improve.

The severity of accidents that involve vehicles penetrating cable guardrails has never been established. However, crash test data and computer simulation results indicate that most guardrail penetrations result in vehicle rollover. Accident data on TxDOT standard W-beam guardrail indicate a fatality rate of 27 percent for impacts involving automobile rollover (23). Although similar data for trucks are not available, accident data collected on rural highways in the state of Washington indicate that only 50 percent of truck rollover accidents involve an injury or fatality (22). These fatality and injury rates were used to assign a severity index of 6.5 for automobile penetration accidents and 3.0 for truck penetration accidents.

Finally, it is necessary to estimate the severity of impact with both roadside slopes and cross-drainage culverts. The next section presents the development of the embankment severities from the accident data previously discussed, which is followed by a discussion of the development of the culvert severities from accident data. Complete details of the formulation of the ABC benefit-cost analysis are available elsewhere (2).

Embankment Severities

Since this study involves the development of embankment warrants for rural roadways in Nebraska, the Michigan accident data on rural roadways were used to generate the embankment severities. In comparison to the other accident data sources discussed, the Michigan embankment data are believed to represent the average roadside characteristics of Nebraska. Both the gross and adjusted Michigan embankment severities by functional class are shown in Table 15. Although research that discusses the adjustment of embankment accident data to account for unreported accidents is currently unavailable, it is well recognized in the roadside safety community that an unknown percentage of embankment accidents go unreported.

Therefore, a one to one relationship for unreported to reported embankment accidents was assumed. This is believed to be a conservative estimate, thus resulting in a more severe embankment severity estimate. The reasoning has two parts. First, the Michigan embankment severities are not as severe as expected. Second, a conservative estimate of embankment severity will produce embankment warrants that are also more conservative. Again, it is assumed that no severe injury or fatal accidents are unreported. Unlike the adjustment of the LBSS cable guardrail accident severities, no initial assumption as to the proportion of unreported moderate and minor injuries was made. Instead the data were adjusted by observing the injury level percentages of the adjusted data. Therefore, some trends in the percentages may be observed. Such as, the percentage of fatal accidents is highest for rural interstates and lowest for rural collectors. This trend continues for severe, moderate and slight injury accidents. However, this trend is reversed for property damage only accidents. This method of adjusting was used to account for the apparently under reported moderate (B) injury accidents.

TABLE 15. GROSS AND ADJUSTED EMBANKMENT SEVERITIES.

PIC Injury Level	Accident Cost	Rural Interstate		Rural Arterial		Rural Collector	
		Michigan Reported	Michigan Adjusted	Michigan Reported	Michigan Adjusted	Michigan Reported	Michigan Adjusted
K	$1,000,000	5	5	15	15	1	1
A	$200,000	90	90	420	420	99	99
B	$12,500	38	190	204	1020	67	134
C	$3,750	206	824	1121	3363	90	405
PDO	$625	1425	2419	4604	7910	450	775
TOTAL		1764	3528	6364	12728	707	1414
Average Accident Cost			$8,497		$10,159		$17,311
Average Severity Index			2.3		2.5		3.0

As previously discussed, the Michigan embankment accident severities appear to increase with decreasing functional class. In a phone conversation with Don Mercer, the main HSIS contact in the Safety Division of the Michigan DOT, it was determined that the average rural interstate embankment accidents probably represent accidents involving a 4:1 side-slope. With less confidence, it was also determined that an average embankment accident on a rural arterial could represent a 3:1 side-slope and that an average embankment accident on a rural collector could represent a 2:1 side-slope. However, after further consideration, it was assumed that embankment accidents on rural interstates, rural arterials, and rural collectors represent side-slopes of 4:1, 3.5:1 and 2.5:1. These assumptions are based partially on engineering judgement and simulation runs with the ABC model to correlate the accident data with the accident prediction algorithm contained in the ABC model. Once the three side-slope severities were linked to the ABC model, severities for other side-slopes were extrapolated, as shown in Table 16. These embankment severities have also been plotted and are presented in Figure 7.

TABLE 16. EMBANKMENT SEVERITY.

Embankment Slope	Average Accident SI	Benefit/ Cost SI/mph	Embankment Height		Embankment Width		Impact Speed (mph)					
			D(ft)	D(m)	W(ft)	W(m)	30	40	50	60	70	80
1.0:1	4.3	0.0957	6.60	2.00	6.60	2.00	2.9	3.8	4.8	5.7	6.7	7.7
1.5:1	3.9	0.0857	6.60	2.00	9.80	3.00	2.6	3.4	4.3	5.1	6.0	6.9
2.0:1	3.4	0.0759	6.60	2.00	13.10	4.00	2.3	3.0	3.8	4.6	5.3	6.1
2.5:1	**3.0**	0.0661	6.60	2.00	16.40	5.00	2.0	2.6	3.3	4.0	4.6	5.3
3.0:1	2.8	0.0563	6.60	2.00	19.70	6.00	1.7	2.3	2.8	3.4	3.9	4.5
3.5:1	**2.5**	0.0461	6.60	2.00	23.00	7.00	1.4	1.8	2.3	2.8	3.2	3.7
4.0:1	**2.3**	0.0390	6.60	2.00	26.20	8.00	1.2	1.6	2.0	2.3	2.7	3.1
4.5:1	2.0	0.0317	5.30	1.60	23.60	7.20	1.0	1.3	1.6	1.9	2.2	2.5
5.0:1	1.3	0.0243	3.90	1.20	19.70	6.00	0.7	1.0	1.2	1.5	1.7	1.9

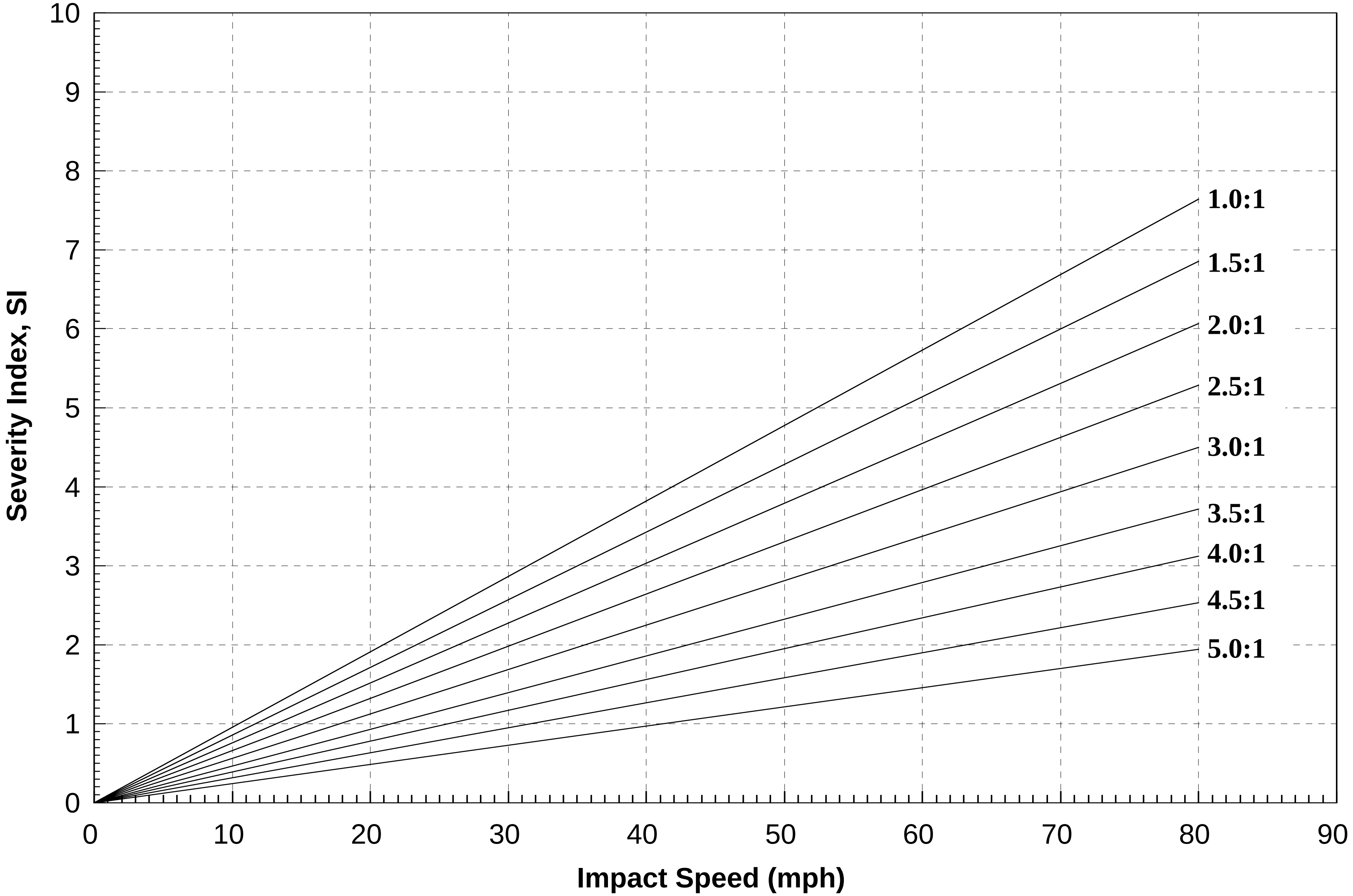

FIGURE 7. SEVERITY OF EMBANKMENT.

The 1995 update to the AASHTO Roadside Design Guide (18) contains suggested embankment severity indices for use with the update to the ROADSIDE benefit/cost analysis program. These values are based almost entirely on engineering judgement. Further it is not appropriate to use these values in encroachment, probability-based, benefit/cost analysis programs that use speed and angle distributions based on functional classification in the accident prediction algorithms, such as both the ABC and the BCAP models. Therefore, the Roadside Design Guide embankment severities for foreslopes, shown in Table 17, were used only to provide a comparison and a format for the embankment severities developed in this report. Note that the format in Table 17 shows that the embankment severities vary by speed, side-slope, and embankment depth. Therefore, it seemed reasonable in this report to vary the embankment severities with embankment depth. As shown in Table 16, embankment heights had to be assumed for each side-slope. When comparing Tables 16 and 17, the average accident severity index from Table 16 should be used in comparison with the severity index at the 50 mph design speed from Table 17. For example, the average accident severity index for a 3:1 side-slope with an embankment depth of 6.6 ft is 2.8 from Table 16, and is 2.8 from the Roadside Design Guide table. However, as shown in the Roadside Design Guide table, steeper side-slopes have more variability regarding embankment depth. In the roadside safety community it is commonly believed that for a given side-slope as the embankment depth increases so does the accident severity. Therefore, curves were assumed that passed through the embankment severities from Table 16 at the assigned embankment depth for each of the corresponding side-slopes, as shown in Figure 8. Although it appears that at an embankment depth of approximately one-half of a foot, that the severity indices

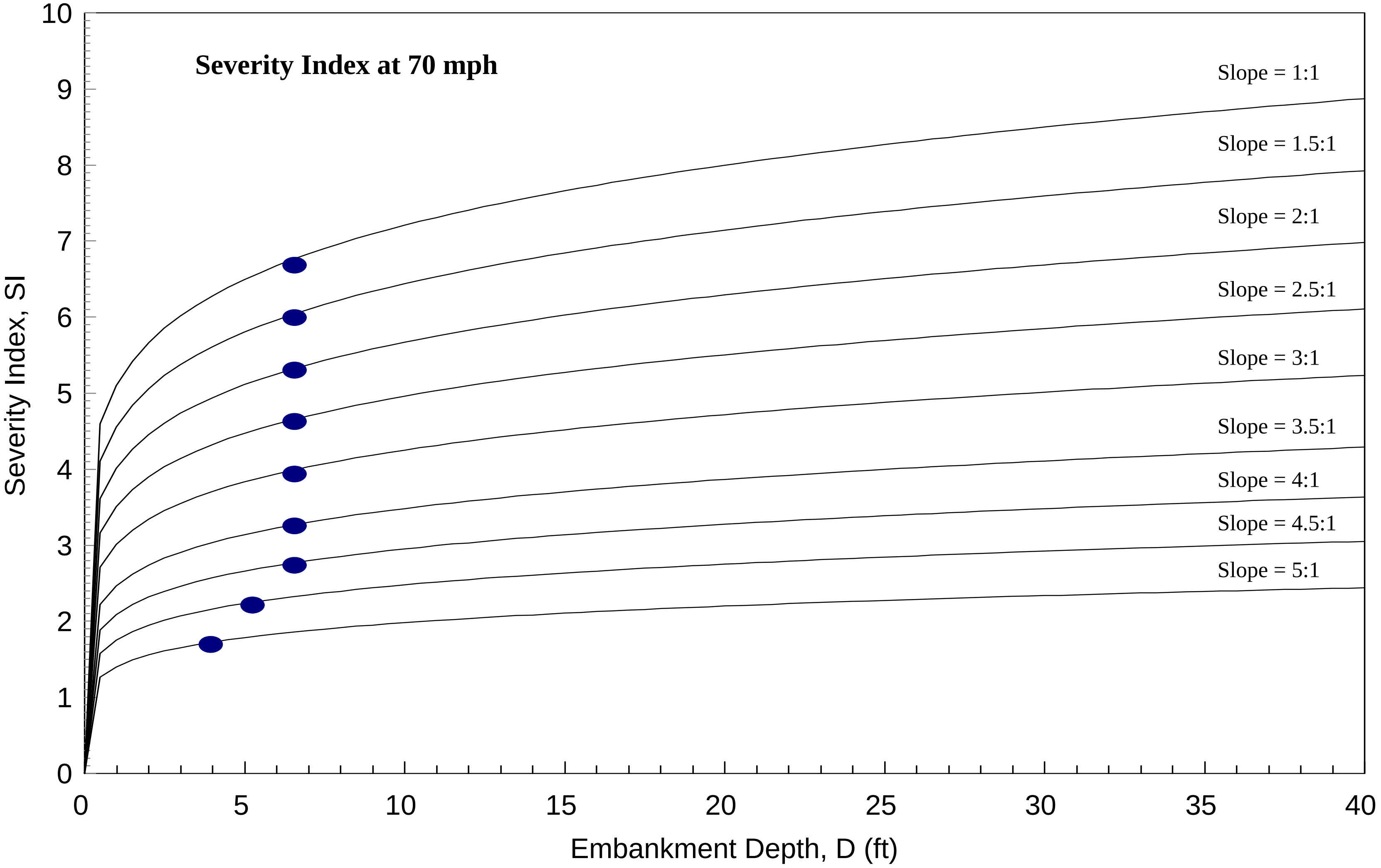

FIGURE 8. SEVERITY OF EMBANKMENT BY DEPTH.

TABLE 17. ROADSIDE DESIGN GUIDE EMBANKMENT SEVERITIES.

Embankment	Embankment Height		Embankment Width		Surface	Design Speed (mph)					
Side-Slope	D (m)	D (ft)	W (m)	W (ft)	Condition	30	40	50	60	70	80
10:1	0.3	0.98	3	9.84	A	0.3	0.6	0.9	1.1	1.4	1.7
8:1	0.3	0.98	2.4	7.87	A	0.3	0.7	1.0	1.4	1.7	2.0
6:1	0.3	0.98	1.8	5.91	A	0.5	0.9	1.3	1.7	2.1	2.5
4:1	2	6.56	8	26.25	A	1.3	1.7	2.0	2.4	2.7	3.1
3:1	2	6.56	6	19.68	A	2.0	2.4	2.8	3.1	3.5	3.9
3:1	4	13.12	12	39.37	A	2.0	2.4	2.9	3.3	3.7	4.1
3:1	6	19.68	18	59.05	A	2.0	2.4	2.9	3.3	3.8	4.3
3:1	10	32.81	30	98.42	A	2.0	2.4	2.9	3.5	4.0	4.5
2:1	2	6.56	4	13.12	A	2.9	3.3	3.8	4.2	4.6	5.0
2:1	4	13.12	8	26.25	A	3.1	3.6	4.0	4.5	5.0	5.4
2:1	6	19.68	12	39.37	A	3.3	3.7	4.2	4.6	5.0	5.5
2:1	10	32.81	20	65.62	A	4.1	4.4	4.7	5.1	5.4	5.7
1.5:1	2	6.56	3	9.84	A	3.3	3.7	4.2	4.7	5.1	5.6
1.5:1	4	13.12	6	19.68	A	3.8	4.2	4.7	5.1	5.5	5.9
1.5:1	6	19.68	9	29.53	A	4.1	4.5	5.0	5.4	5.8	6.2
1.5:1	8	26.25	12	39.37	A	4.3	4.7	5.2	5.6	6.0	6.4
1.5:1	10	32.81	15	49.21	A	4.8	5.3	5.7	6.2	6.7	7.1

on the curves rapidly decrease and are possibly unreasonable. It must be remembered that these curves represent the variation of severity with both embankment depth and side-slope at an impact speed of 70 mph. For lower impact speeds the curves show a much more gradual decrease. Presented in Appendix C is a table of the developed embankment severities as a function of embankment depth, side-slope, and impact speed, as shown in Figure 8.

Culvert Severities

The development of culvert warrants requires estimates of culvert severities. As discussed in the accident data analysis section, the use of the Utah bridge/culvert accidents is believed to be appropriate in the development of culvert severities. The Michigan and Perchonok data were also used in the development of the culvert severities. Originally, a relationship between culvert severity and functional class was sought, so the Perchonok culvert accidents were assumed to have occurred on rural collector roadways based on information in the report (9). The gross culvert accident severities classified by functional class and state of origin are shown in Table 18. The Perchonok culvert severities, which are more severe than either the Utah or Michigan data, were included to introduce conservatism into the culvert severities. It was later found that there was no correlation between the culvert severities and functional classification. Therefore, all of the available culvert data were combined and used to represent an average culvert accident. Research regarding the adjustment of culvert accidents to estimate the number of unreported accidents is not currently available. It is intuitive that culvert accidents are reported more than embankment accidents due to the higher severity usually assigned to culvert accidents. Further, culvert accidents, although infrequent, should produce a lower percentage of property

TABLE 18. GROSS CULVERT SEVERITIES.

Rural Interstate		Rural Arterial		Rural Collector			
Michigan	Utah	Michigan	Utah	Michigan	Utah	Perchonok	Total
1	2	8	5	1	5	14	36
5	40	92	35	3	17	63	255
1	32	26	22	3	29	18	131
8	18	81	16	3	16	49	191
27	119	196	83	11	66	87	589
42	211	403	161	21	133	231	1202

damage only accidents than embankment accidents. Recall that it was assumed that 50% of all embankment accidents were assumed to go unreported. Estimates by some researchers in the roadside safety community estimate that possibly as many as eight embankment accidents in one go unreported. These same researchers also estimate the culvert reporting ratio may be 2:1. In this report it is assumed that only fifty percent of all culvert accidents are reported. This estimate is still thought to be a conservative estimate because of the inclusion of the Perchonok data. It was assumed that neither fatal culvert accidents nor severe injury accidents went unreported. The adjusted culvert severities are shown in Table 19. These data were adjusted by observing the injury level percentages along with the property damage percentages. Thus, of the unreported accidents, 22% were moderate injury accidents and 32% were minor injury accidents.

TABLE 19. ADJUSTED CULVERT SEVERITY.

PIC Injury Level	Accident Cost	Gross Reported Accidents	Percent Reported TOTAL	Adjusted Accidents	Percent of Adjusted Accidents
K	$1,000,000	36	3.0%	36	1.5%
A	$200,000	255	21.2%	255	10.6%
B	$12,500	131	10.9%	393	16.4%
C	$3,750	191	15.9%	573	23.8%
PDO	$625	589	49.0%	1147	47.7%
TOTAL		1202	100.0%	2404	100.0%
Average Accident Cost				$39,425	
Average Severity Index				3.8	

The 1995 update to the Roadside Design Guide (18) also contains suggested culvert severity indices for use with the update to the ROADSIDE benefit/cost analysis program. Again, these values are based almost entirely on engineering judgement and are not appropriate for use in the ABC benefit/cost model. Therefore, the Roadside Design Guide culvert severities, shown in Table 20, were used only to provide a comparison and a format for the embankment severities developed in this report. The format shows that the culvert severity is a function of culvert size and speed. Note that the ROADSIDE program requires severities to be entered as a function of the hazard surface. The ABC model uses the hazard imaging technique; therefore, severities developed in this report are not required to be entered as a function of the hazard surface. Thus, in this report the culvert severities were developed as a function of culvert size and impact speed, as shown in Table 21. Since it is believed that culverts 3 feet in height are the most common culvert installed and are not likely to be shielded with guardrail, the average culvert

TABLE 20. ROADSIDE DESIGN GUIDE CULVERT SEVERITY.

Hazard Type and Characteristics			Hazard Surface	Transverse Culvert Severities: End Type A					
Culvert Height				Design Speed (mph)					
(m)	(ft)	(in)		30	40	50	60	70	80
0.5	1.6	18	S	0.5	0.8	1.1	1.3	1.6	1.9
0.6	2.0	24	S	1.4	2.0	2.6	3.1	3.7	4.3
1	3.0	36	S	2.0	2.7	3.4	**4.1**	4.8	5.5
1.2	4	48	S	2.4	3.2	3.9	4.7	5.5	6.2
1.8	6	72	S	2.7	3.5	4.3	5.1	5.9	6.8
2.4	8	96	S	2.9	3.7	4.6	5.4	6.3	7.1

TABLE 21. CULVERT SEVERITY

Hazard Type and Characteristics			Severity Index						Average Accident SI
Culvert Height			Design Speed (mph)						
(m)	(ft)	(in)	30	40	50	60	70	80	
0.5	1.6	18	1.0	1.3	1.6	2.0	2.3	2.6	2.0
0.6	2.0	24	1.6	2.1	2.7	3.2	3.7	4.2	2.9
1.0	3.0	36	2.0	2.7	3.4	4.0	4.7	5.4	**3.8**
1.2	3.9	48	2.3	3.1	3.9	4.7	5.5	6.2	4.3
1.8	5.9	72	2.6	3.4	4.3	5.1	6.0	6.8	4.7
2.4	7.9	96	2.7	3.6	4.6	5.5	6.4	7.3	5.0
3.0	9.8	120	2.9	3.8	4.8	5.8	6.7	7.7	5.6

accident severity was assumed to represent an average accident involving a culvert 3 feet in height. Runs with the ABC model were then used to both correlate and extrapolate the culvert severities to culverts of other sizes. To compare the two tables, the average culvert accident severity index from Table 21 should be compared with the severities at a design speed of 50 mph from Table 20. This comparison shows that the severities developed in this report are slightly more severe for both smaller and larger culverts when compared with the severities from the Roadside Design Guide. The culvert severities developed in this report have been plotted, as in Figure 9.

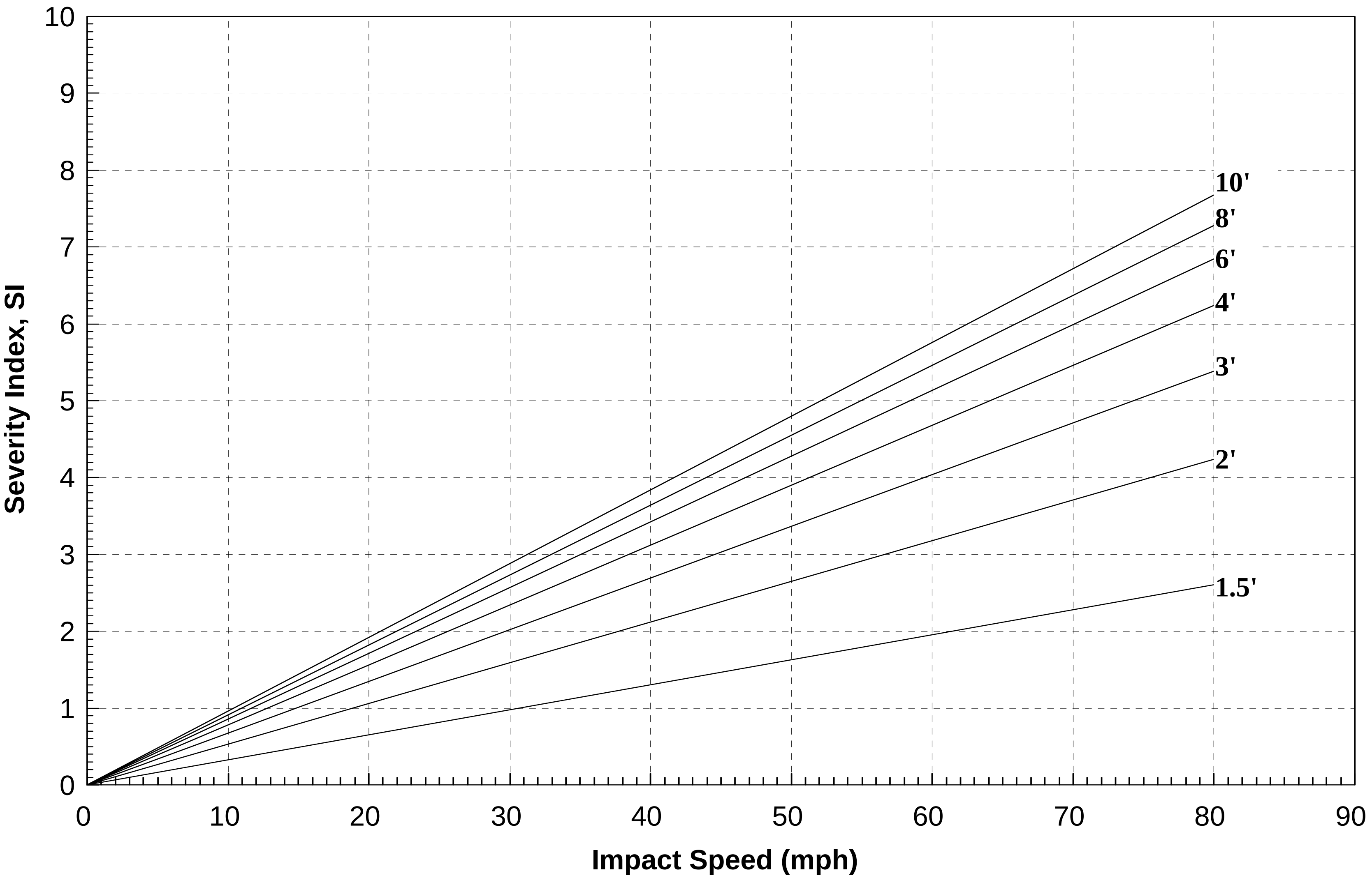

FIGURE 9. SEVERITY OF CULVERT.

Design Charts.

The main objective of this report and the benefit/cost analysis was to develop simplified warranting charts for warranting cable and w-beam guardrail for roadside slopes and w-beam guardrail for cross-drainage culverts on rural low-volume roadways. The first step in developing the warranting charts involved examining the sensitivity of both embankment warranting and culvert warranting to various roadway and roadside variables. Variables found to have a significant effect on embankment warranting are listed in Table 22, and are classified by significance. However, some of these variables are strongly correlated, such as the offset to the face of the guardrail, L_Y, the offset to the back of the embankment, L_H, and the width of the embankment hazard, W. Thus, the importance of some of these variables may be eliminated by controlling other parameters.

TABLE 22. EMBANKMENT SENSITIVITY.

Description	Variable
Embankment Hazard Width	W_2
Embankment Slope	Slope
Average Annual Daily Traffic	ADT
Length of Cable Guardrail	CabL
Lateral Offset to Face of Embankment hazard	Y_2
Embankment Length	EmbL
Lateral Offset Difference	$L_{OD} = L_H - L_Y$
Lateral Offset to Back of Embankment Hazard	L_H
Lateral Offset to Face of Guardrail	L_Y

An important variable required in both the embankment sensitivity analysis and the embankment warranting procedure is the length of guardrail to be installed. These values were calculated using previous research that this researcher conducted (24). The upstream guardrail length-of-need was determined from Figure 10. A similar figure for the downstream length-of-need is contained in the previously cited report. Figure 10 shows that the length-of-need is a function of traffic volume, lateral offset difference, and the traffic volume. Additional information regarding the development and usage of the length-of-need charts is available elsewhere (24) and will not be presented here.

The variables found to have a significant effect were then systematically evaluated to determine the variables or combination of variables that had the most effect on the embankment warranting procedure. This process involved holding a combination of variables constant and evaluating the sensitivity of the cable guardrail warrant to all other variables found to have a significant influence. This process ultimately lead to the conclusion that embankment warrants are relatively insensitive to changes in other variables when traffic volume, embankment width, and embankment slope are held constant.

The ABC model was then used to develop a warranting chart for embankments as a function of these three variables. This process involved using the ABC model for a wide variety of roadside situations to determine when cable guardrail is warranted to shield embankments. The results of this analysis were then fitted visually, and are shown in Figure 11. A similar chart was also developed for w-beam guardrail protection of embankment slopes as is shown in Figure 12. The shape and nature of the guardrail need for embankment curves allowed them to be simplified into tables. The cable and w-beam guardrail need for embankments is shown in Table 23.

TABLE 23. GUARDRAIL NEED FOR EMBANKMENTS.

SIDE	PROTECTION IS WARRANTED WHEN	
SLOPE	CABLE GUARDRAIL	W-BEAM GUARDRAIL
1.0:1	ADT $\geq$ 500 AND Depth $\geq$ 4 ft	ADT $\geq$ 1000 AND Depth $\geq$ 5 ft
1.5:1	ADT $\geq$ 500 AND Depth $\geq$ 4 ft	ADT $\geq$ 3000 AND Depth $\geq$ 11 ft
2.0:1	ADT $\geq$ 1200 AND Depth $\geq$ 6 ft	NA
2.5:1	ADT $\geq$ 2000 AND Depth $\geq$ 10 ft	NA

Initially, a significant effort was made to develop culvert warrants that included the previously mentioned embankment variables into a single chart. Ideally this chart would be a function of culvert size, traffic volume, lateral offset to the face of the culvert, and the embankment width. However, this effort was unsuccessful. The primary reason is that the guardrail length was designed to shield the embankment which contained the culvert, thus resulting in longer guardrail installations. This resulted in essentially the same figure obtained for embankment warrants.

Therefore, it was determined that a single chart for culvert warrants would be developed in which the w-beam guardrail length was designed to shield the culvert and the effect of embankments was neglected. The variables found to have a significant effect on culvert warranting are listed in Table 24, and are classified by significance. Again, some of these variables are strongly correlated. The importance of some of these variables was eliminated by controlling other parameters.

TABLE 24. CULVERT SENSITIVITY.

Description	Variable
Culvert Size, Width	W_2
Lateral Offset to Face of Culvert Hazard	Y_2
Average Annual Daily Traffic	ADT
Length of Cable Guardrail	CabL
Lateral Offset Difference	$L_{od} = L_H - L_Y$
Lateral Offset to Back of Hazard	L_H
Lateral Offset to Face of Guardrail	L_Y

Variables found to have a significant effect on culvert warrants were systematically evaluated to determine the variables or combination of variables that had the most effect on the culvert warranting procedure. This process involved holding a combination of variables constant and evaluating the sensitivity of the w-beam guardrail warrant to all other variables found to have a significant influence. This process finally lead to the conclusion that culvert warrants are relatively insensitive to changes in other variables when traffic volume, lateral offset to the face of the culvert and culvert size are held constant.

A warranting chart for culverts was then developed as a function of these three variables using the ABC model. A wide variety of roadside situations were evaluated using the ABC model to determine when w-beam guardrail is warranted to shield culverts. The result of this analysis were then visually fitted, and is shown in Figure 13.

The application of the charts shown in Figures 11, 12 and 13 should be simple to apply. First, this process involves identifying possible areas where cable guardrail warranting applies for an embankment and w-beam guardrail warranting applies for either a culvert or an embankment.

As discussed in the Roadside Design Guide, guardrail should only be considered if a roadside hazard cannot be eliminated, redesigned to reduce the hazard, or moved out of the clear zone. Since eliminating or redesigning an embankment hazard is usually quite costly and moving it out of the clear zone is not an option, the use of Figures 11 and 12 to determine whether shielding the embankment with a guardrail is a simple process. Similarly, the application of the culvert chart, Figure 13, is also relatively straight forward. However, engineering judgement must be used when both an embankment and a culvert are present, though neither warrant protection with guardrail.

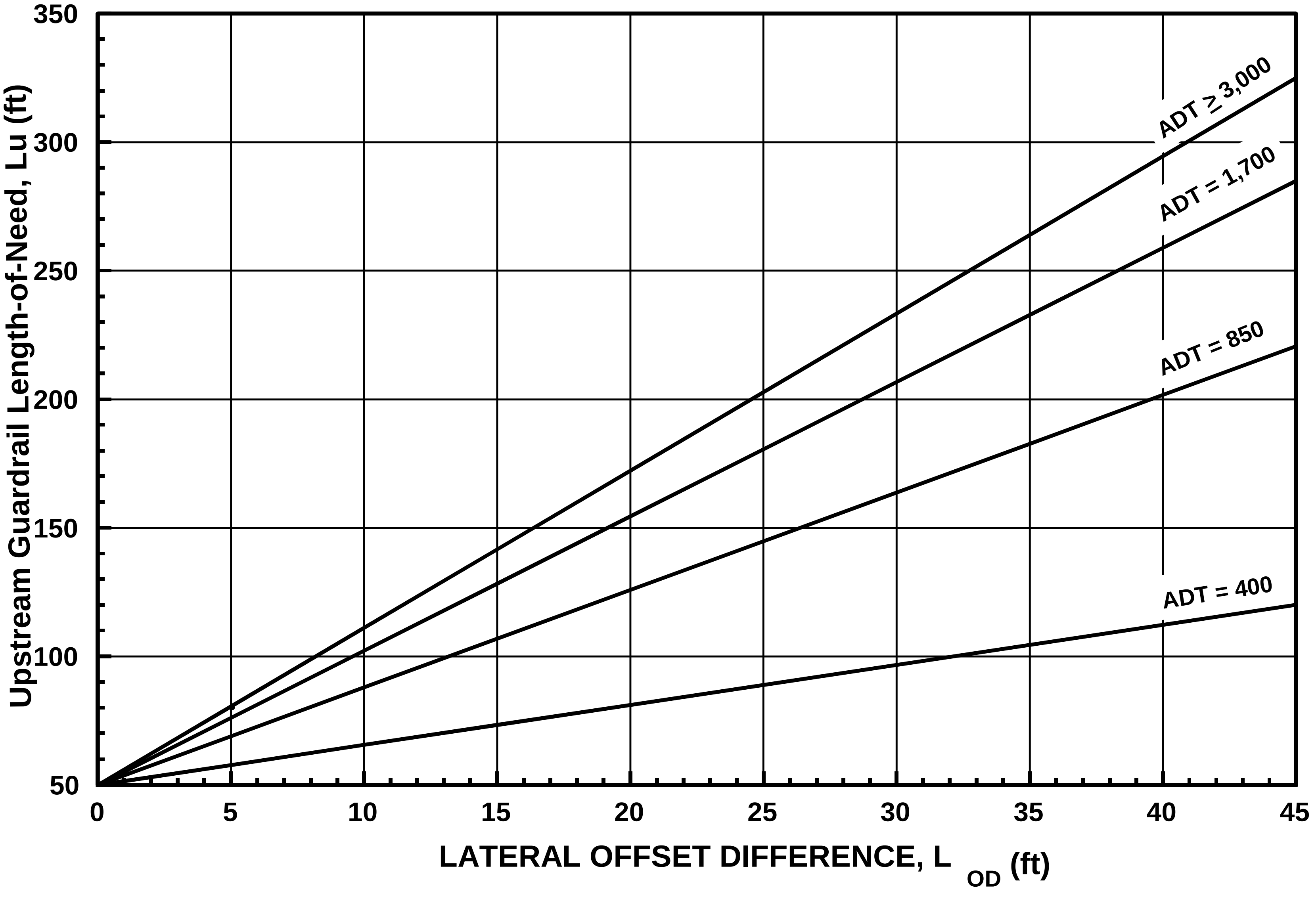

FIGURE 10. UPSTREAM GUARDRAIL LENGTH-OF-NEED DESIGN CHART.

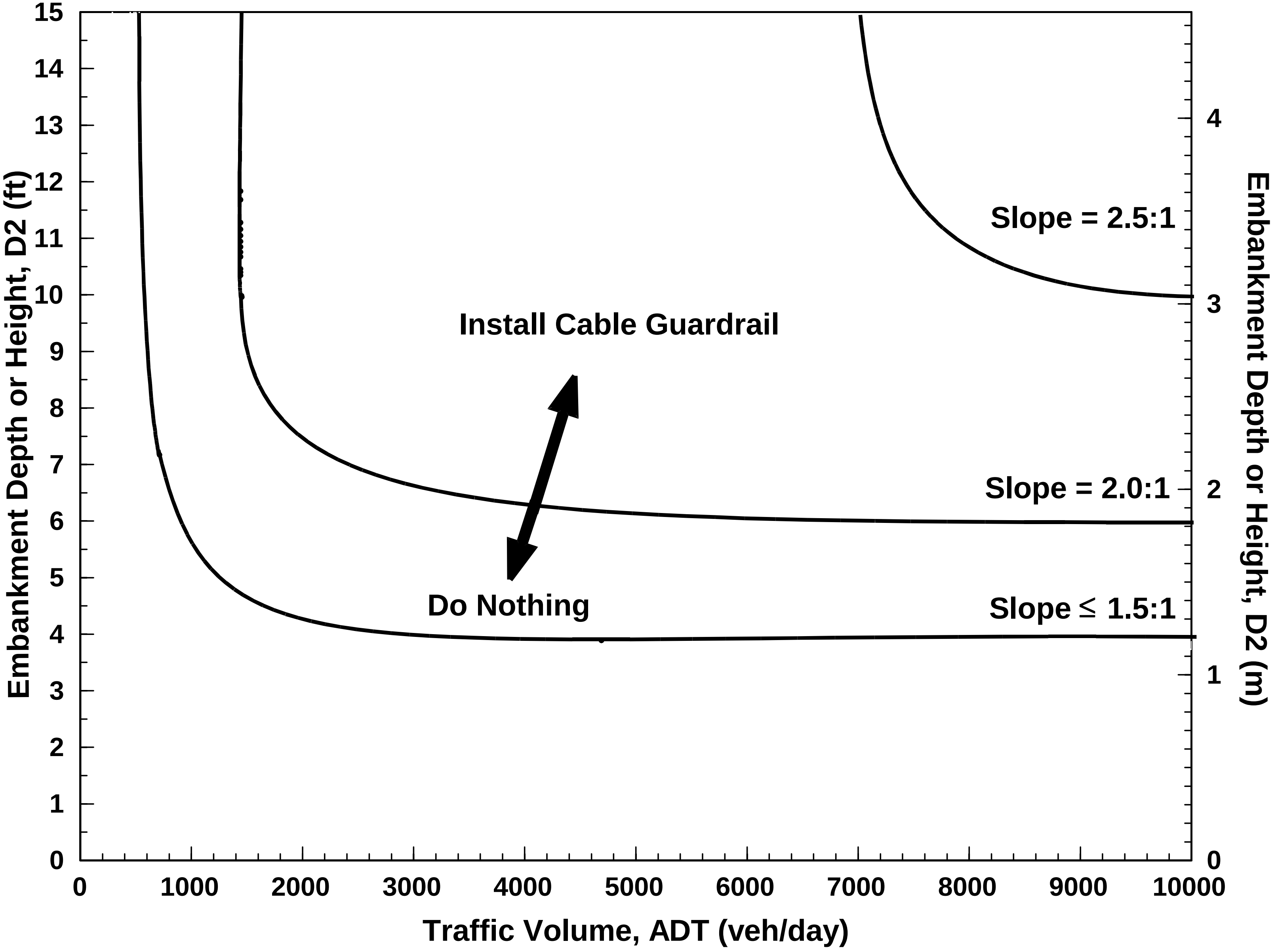

FIGURE 11. CABLE GUARDRAIL NEED FOR EMBANKMENTS.

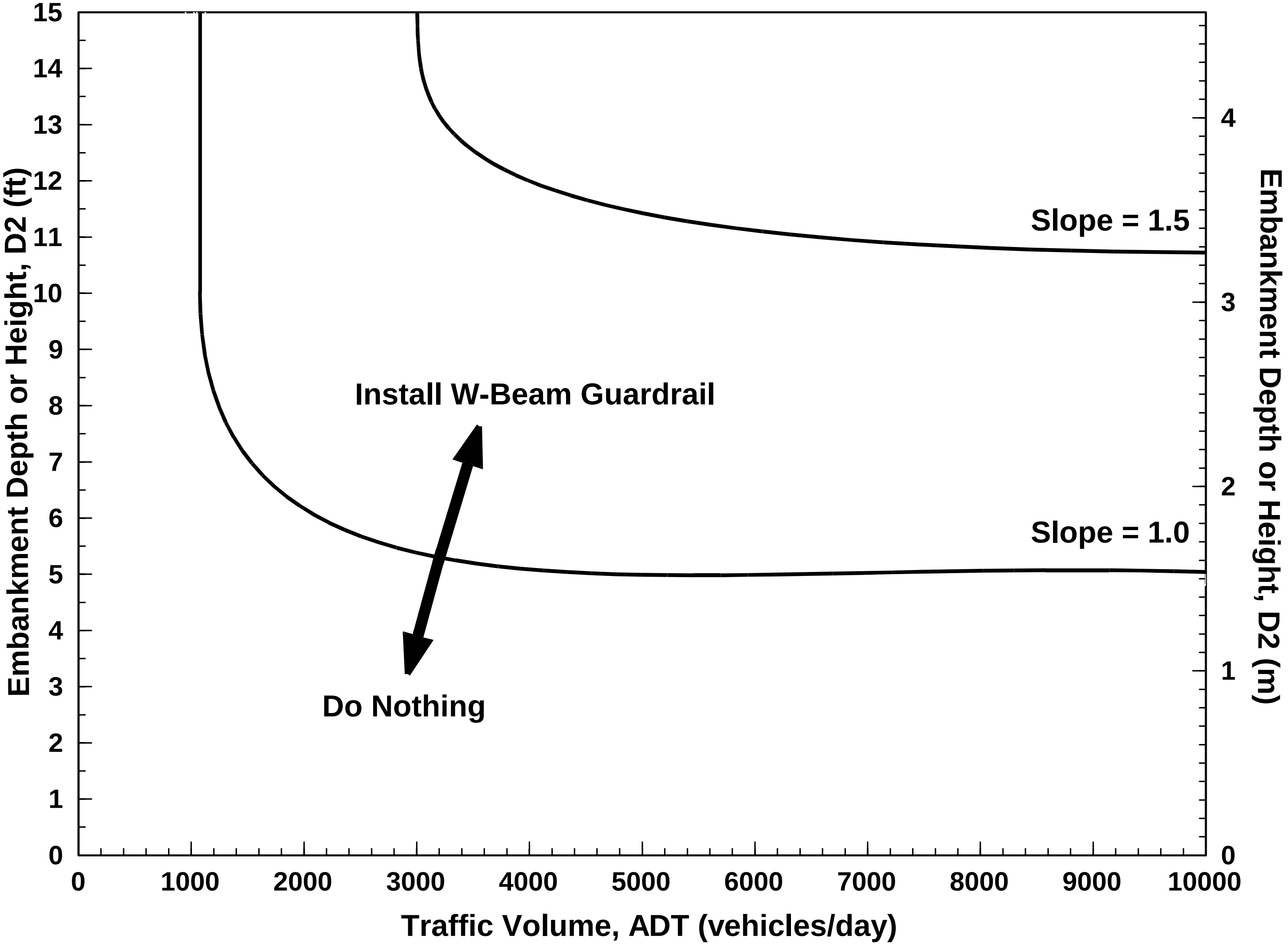

FIGURE 12. W-BEAM GUARDRAIL NEED FOR EMBANKMENTS.

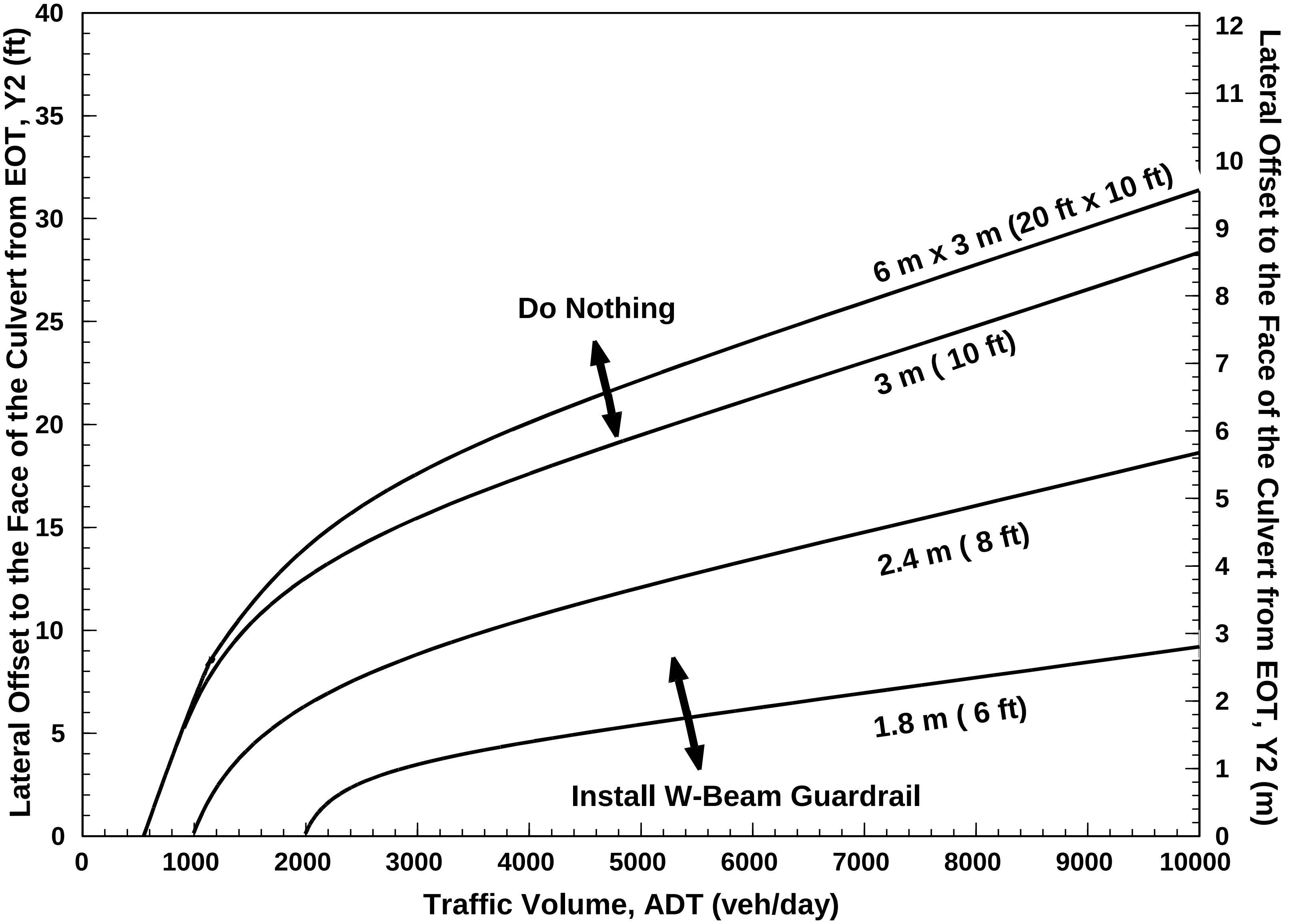

FIGURE 13. W-BEAM GUARDRAIL NEED FOR CULVERTS.
Note: Culverts with a rise less than 1.8 m were not cost-beneficial.

CHAPTER 5. CONCLUSIONS

The guidelines for using cable guardrail to shield traffic from roadside embankments and w-beam guardrail to shield traffic from embankments and culverts should provide a simplified technique for use in 3R project development. These curves are intended to eliminate the need for conducting benefit/cost analysis in these situations. Further, these guidelines should lead to more appropriate safety improvement decisions than were possible with the use of the relatively simplistic Roadside computer program. The guidelines described in this paper are intended to be a tool to aid designers in the decision making process. However, there are situations where these guidelines may not be appropriate. For example, when very large hazards exist on the slope, the slope is no longer the controlling factor, instead the analysis is controlled by the severity of the other hazard. Finally, the guidelines developed under this study could be greatly improved when more accurate embankment severity estimates become available at the conclusion of NCHRP Project 17-11 (18).

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APPENDIX

A. Gross Michigan Accident Data by Functional Class

B. Gross Utah Accident Data by Functional Class

C. Embankment Severities classified by Depth.

APPENDIX A.
Gross Michigan Accident Data by Functional Class

MICHIGAN 1985-1991 FUNC_CLS = 1 = RURAL- PRIMARY ARTERIAL-INTERSTATE

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	VEH_OBJ CODE#	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
		FATAL 1	INJURY LEVEL			PDO 5				
			A=2	B=3	C=4					
No object hit	1	63	601	277	1093	11240	13274	0.5%	5.0%	15.3%
Guardrail or guard post	2	11	121	56	308	1775	2271	0.5%	5.8%	21.8%
Highway Sign	3	0	23	10	45	425	503	0.0%	4.6%	15.5%
Street light, Utility Pole	4	0	7	1	5	69	82	0.0%	8.5%	15.9%
Culvert	5	1	5	1	8	27	42	2.4%	14.3%	35.7%
Ditch, Embankment, Stream	6	5	90	38	206	1425	1764	0.3%	5.4%	19.2%
Bridge Pier or Abutment	7	2	7	0	14	72	95	2.1%	9.5%	24.2%
Bridge rail or deck	8	1	5	3	23	101	133	0.8%	4.5%	24.1%
Tree	9	10	61	30	90	404	595	1.7%	11.9%	32.1%
Highway or railroad signal	10	0	0	0	0	2	2	0.0%	0.0%	0.0%
Building	11	0	0	1	0	3	4	0.0%	0.0%	25.0%
Mailbox	12	0	1	1	1	13	16	0.0%	6.3%	18.8%
Fence	13	2	11	4	36	166	219	0.9%	5.9%	24.2%
Traffic island or curb	14	0	1	0	2	19	22	0.0%	4.5%	13.6%
Concrete median barrier	15	0	16	16	77	351	460	0.0%	3.5%	23.7%
Other on-trafficway object	16	10	33	11	71	1150	1275	0.8%	3.4%	9.8%
Other-off-trafficway object	17	0	14	4	25	257	300	0.0%	4.7%	14.3%
Overhead fixed object	18	0	0	0	0	16	16	0.0%	0.0%	0.0%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	20	36	5	19	7	87	23.0%	64.4%	92.0%
	TOTAL	125	1032	458	2023	17522	21160	0.6%	5.5%	17.2%

MICHIGAN 1985-1991 FUNC_CLS = 2 = RURAL- PRIMARY ARTERIAL-OTHER

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	VEH_OBJ CODE#	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
		FATAL 1	INJURY LEVEL			PDO 5				
			A=2	B=3	C=4					
No object hit	1	105	875	354	1464	34338	37136	0.3%	2.6%	7.5%
Guardrail or guard post	2	10	105	104	265	1483	1967	0.5%	5.8%	24.6%
Highway Sign	3	3	27	19	89	816	954	0.3%	3.1%	14.5%
Street light, Utility Pole	4	5	49	8	98	324	484	1.0%	11.2%	33.1%
Culvert	5	4	33	9	38	67	151	2.6%	24.5%	55.6%
Ditch,Embankment,Stream	6	9	174	90	468	2128	2869	0.3%	6.4%	25.8%
Bridge Pier or Abutment	7	1	5	5	11	52	74	1.4%	8.1%	29.7%
Bridge rail or deck	8	0	7	2	19	70	98	0.0%	7.1%	28.6%
Tree	9	18	171	66	216	841	1312	1.4%	14.4%	35.9%
Highway or railroad signal	10	0	4	0	3	6	13	0.0%	30.8%	53.8%
Building	11	1	6	2	7	48	64	1.6%	10.9%	25.0%
Mailbox	12	1	44	17	76	761	899	0.1%	5.0%	15.4%
Fence	13	1	15	4	31	214	265	0.4%	6.0%	19.2%
Traffic island or curb	14	2	3	1	7	71	84	2.4%	6.0%	15.5%
Concrete median barrier	15	0	10	10	38	196	254	0.0%	3.9%	22.8%
Other on-trafficway object	16	5	29	7	69	1049	1159	0.4%	2.9%	9.5%
Other-off-trafficway object	17	1	16	13	39	360	429	0.2%	4.0%	16.1%
Overhead fixed object	18	0	1	0	3	67	71	0.0%	1.4%	5.6%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	55	132	17	58	24	286	19.2%	65.4%	91.6%
	TOTAL	221	1706	728	2999	42915	48569	0.5%	4.0%	11.6%

MICHIGAN 1985-1991 FUNC_CLS = 6 = RURAL-MINOR ARTERIAL

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

		SEVERITY								
OBJECT VEHICLE HIT	**VEH_OBJ**	**FATAL**	**INJURY LEVEL**			**PDO**				
	CODE#	**1**	**A=2**	**B=3**	**C=4**	**5**	**TOTAL**	**%(K)**	**%(K+A)**	**%(K+I)**
No object hit	1	121	1024	302	1681	48746	51874	0.2%	2.2%	6.0%
Guardrail or guard post	2	15	63	32	180	999	1289	1.2%	6.1%	22.5%
Highway Sign	3	9	67	20	120	1022	1238	0.7%	6.1%	17.4%
Street light, Utility Pole	4	10	100	41	121	637	909	1.1%	12.1%	29.9%
Culvert	5	4	59	17	43	129	252	1.6%	25.0%	48.8%
Ditch,Embankment,Stream	6	6	246	114	653	2476	3495	0.2%	7.2%	29.2%
Bridge Pier or Abutment	7	0	5	1	8	26	40	0.0%	12.5%	35.0%
Bridge rail or deck	8	1	2	3	10	48	64	1.6%	4.7%	25.0%
Tree	9	55	347	107	452	1304	2265	2.4%	17.7%	42.4%
Highway or railroad signal	10	0	0	0	3	15	18	0.0%	0.0%	16.7%
Building	11	1	18	4	20	72	115	0.9%	16.5%	37.4%
Mailbox	12	8	72	38	155	1416	1689	0.5%	4.7%	16.2%
Fence	13	3	37	10	65	342	457	0.7%	8.8%	25.2%
Traffic island or curb	14	1	5	2	6	132	146	0.7%	4.1%	9.6%
Concrete median barrier	15	0	1	2	3	27	33	0.0%	3.0%	18.2%
Other on-trafficway object	16	3	36	5	48	750	842	0.4%	4.6%	10.9%
Other-off-trafficway object	17	8	35	4	51	415	513	1.6%	8.4%	19.1%
Overhead fixed object	18	0	0	0	2	52	54	0.0%	0.0%	3.7%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	80	250	23	139	50	542	14.8%	60.9%	90.8%
	TOTAL	325	2367	725	3760	58658	65835	0.5%	4.1%	10.9%

MICHIGAN 1985-1991 FUNC_CLS = 7 = RURAL-MAJOR COLLECTOR

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

		SEVERITY								
OBJECT VEHICLE HIT	**VEH_OBJ**	**FATAL**	**INJURY LEVEL**			**PDO**				
	CODE#	**1**	**A=2**	**B=3**	**C=4**	**5**	**TOTAL**	**%(K)**	**%(K+A)**	**%(K+I)**
No object hit	1	19	165	152	347	6893	7576	0.3%	2.4%	9.0%
Guardrail or guard post	2	2	10	4	29	122	167	1.2%	7.2%	26.9%
Highway Sign	3	2	7	1	25	198	233	0.9%	3.9%	15.0%
Street light, Utility Pole	4	1	11	5	22	634	673	0.1%	1.8%	5.8%
Culvert	5	1	3	3	3	11	21	4.8%	19.0%	47.6%
Ditch,Embankment,Stream	6	1	99	67	90	450	707	0.1%	14.1%	36.4%
Bridge Pier or Abutment	7	0	0	0	0	5	5	0.0%	0.0%	0.0%
Bridge rail or deck	8	0	0	0	0	9	9	0.0%	0.0%	0.0%
Tree	9	11	49	24	54	426	564	2.0%	10.6%	24.5%
Highway or railroad signal	10	1	0	0	1	3	5	20.0%	20.0%	40.0%
Building	11	0	1	0	0	13	14	0.0%	7.1%	7.1%
Mailbox	12	3	15	2	15	219	254	1.2%	7.1%	13.8%
Fence	13	3	5	2	7	69	86	3.5%	9.3%	19.8%
Traffic island or curb	14	0	0	2	1	11	14	0.0%	0.0%	21.4%
Concrete median barrier	15	0	0	0	0	5	5	0.0%	0.0%	0.0%
Other on-trafficway object	16	0	1	4	5	203	213	0.0%	0.5%	4.7%
Other-off-trafficway object	17	1	2	2	4	461	470	0.2%	0.6%	1.9%
Overhead fixed object	18	0	1	0	0	7	8	0.0%	12.5%	12.5%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	10	40	7	12	13	82	12.2%	61.0%	84.1%
	TOTAL	55	409	275	615	9752	11106	0.5%	4.2%	12.2%

MICHIGAN 1985-1991 FUNC_CLS = 11 = URBAN-PRIMARY ARTERIAL-INTERSTATE

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	VEH_OBJ CODE#	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
		FATAL 1	INJURY LEVEL			PDO 5				
			A=2	B=3	C=4					
No object hit	1	87	683	251	1075	6954	9050	1.0%	8.5%	23.2%
Guardrail or guard post	2	15	203	78	619	3127	4042	0.4%	5.4%	22.6%
Highway Sign	3	8	27	16	66	542	659	1.2%	5.3%	17.8%
Street light, Utility Pole	4	3	23	10	31	157	224	1.3%	11.6%	29.9%
Culvert	5	0	7	2	5	30	44	0.0%	15.9%	31.8%
Ditch,Embankment,Stream	6	1	89	33	272	1460	1855	0.1%	4.9%	21.3%
Bridge Pier or Abutment	7	4	13	4	39	120	180	2.2%	9.4%	33.3%
Bridge rail or deck	8	2	6	2	29	132	171	1.2%	4.7%	22.8%
Tree	9	6	35	17	82	272	412	1.5%	10.0%	34.0%
Highway or railroad signal	10	1	1	0	1	5	8	12.5%	25.0%	37.5%
Building	11	0	2	0	1	11	14	0.0%	14.3%	21.4%
Mailbox	12	0	0	1	0	13	14	0.0%	0.0%	7.1%
Fence	13	3	21	5	41	243	313	1.0%	7.7%	22.4%
Traffic island or curb	14	0	6	2	30	136	174	0.0%	3.4%	21.8%
Concrete median barrier	15	16	368	198	1047	3222	4851	0.3%	7.9%	33.6%
Other on-trafficway object	16	7	59	25	128	2135	2354	0.3%	2.8%	9.3%
Other-off-trafficway object	17	0	17	17	51	415	500	0.0%	3.4%	17.0%
Overhead fixed object	18	0	3	0	5	52	60	0.0%	5.0%	13.3%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	48	108	19	54	13	242	19.8%	64.5%	94.6%
	TOTAL	201	1671	680	3576	19039	25167	0.8%	7.4%	24.3%

MICHIGAN 1985-1991 FUNC_CLS = 12 = URBAN-PRIMARY ARTERIAL-OTHER/FREEWAY

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	VEH_OBJ CODE#	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
		FATAL 1	INJURY LEVEL			PDO 5				
			A=2	B=3	C=4					
No object hit	1	52	357	118	606	4273	5406	1.0%	7.6%	21.0%
Guardrail or guard post	2	5	72	15	245	945	1282	0.4%	6.0%	26.3%
Highway Sign	3	3	14	6	34	328	385	0.8%	4.4%	14.8%
Street light, Utility Pole	4	1	25	4	35	130	195	0.5%	13.3%	33.3%
Culvert	5	0	4	0	4	14	22	0.0%	18.2%	36.4%
Ditch,Embankment,Stream	6	1	44	20	140	663	868	0.1%	5.2%	23.6%
Bridge Pier or Abutment	7	2	10	1	18	55	86	2.3%	14.0%	36.0%
Bridge rail or deck	8	1	1	1	17	53	73	1.4%	2.7%	27.4%
Tree	9	6	37	12	47	164	266	2.3%	16.2%	38.3%
Highway or railroad signal	10	0	0	0	1	4	5	0.0%	0.0%	20.0%
Building	11	0	1	1	6	22	30	0.0%	3.3%	26.7%
Mailbox	12	0	1	1	3	32	37	0.0%	2.7%	13.5%
Fence	13	2	8	5	23	161	199	1.0%	5.0%	19.1%
Traffic island or curb	14	0	7	1	26	133	167	0.0%	4.2%	20.4%
Concrete median barrier	15	0	110	45	310	994	1459	0.0%	7.5%	31.9%
Other on-trafficway object	16	1	21	11	50	716	799	0.1%	2.8%	10.4%
Other-off-trafficway object	17	0	12	8	24	183	227	0.0%	5.3%	19.4%
Overhead fixed object	18	1	2	0	2	35	40	2.5%	7.5%	12.5%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	30	72	6	56	18	182	16.5%	56.0%	90.1%
	TOTAL	105	798	255	1647	8923	11728	0.9%	7.7%	23.9%

MICHIGAN 1985-1991 FUNC_CLS = 14 = URBAN PRIMARY ARTERIAL OTHERS

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	VEH_OBJ	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
		FATAL	INJURY LEVEL			PDO				
	CODE#	1	A=2	B=3	C=4	5				
No object hit	1	160	787	219	998	2892	5056	3.2%	18.7%	42.8%
Guardrail or guard post	2	8	68	18	182	1062	1338	0.6%	5.7%	20.6%
Highway Sign	3	13	59	22	133	1295	1522	0.9%	4.7%	14.9%
Street light, Utility Pole	4	20	168	66	281	867	1402	1.4%	13.4%	38.2%
Culvert	5	1	17	2	13	58	91	1.1%	19.8%	36.3%
Ditch,Embankment,Stream	6	7	97	63	320	1652	2139	0.3%	4.9%	22.8%
Bridge Pier or Abutment	7	1	6	5	17	80	109	0.9%	6.4%	26.6%
Bridge rail or deck	8	2	5	1	22	98	128	1.6%	5.5%	23.4%
Tree	9	26	138	44	172	592	972	2.7%	16.9%	39.1%
Highway or railroad signal	10	1	6	0	0	23	30	3.3%	23.3%	23.3%
Building	11	1	18	7	24	125	175	0.6%	10.9%	28.6%
Mailbox	12	3	35	13	94	917	1062	0.3%	3.6%	13.7%
Fence	13	2	20	5	42	287	356	0.6%	6.2%	19.4%
Traffic island or curb	14	2	18	10	63	752	845	0.2%	2.4%	11.0%
Concrete median barrier	15	3	127	55	314	772	1271	0.2%	10.2%	39.3%
Other on-trafficway object	16	3	45	10	82	1074	1214	0.2%	4.0%	11.5%
Other-off-trafficway object	17	4	34	13	71	434	556	0.7%	6.8%	21.9%
Overhead fixed object	18	1	0	0	1	78	80	1.3%	1.3%	2.5%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	130	414	71	270	69	954	13.6%	57.0%	92.8%
	TOTAL	388	2062	624	3099	13127	19300	2.0%	12.7%	32.0%

MICHIGAN 1985-1991 FUNC_CLS = 16 = URBAN-MINOR ARTERIAL

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	VEH_OBJ	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
		FATAL	INJURY LEVEL			PDO				
	CODE#	1	A=2	B=3	C=4	5				
No object hit	1	4	18	12	50	457	541	0.7%	4.1%	15.5%
Guardrail or guard post	2	0	0	4	4	30	38	0.0%	0.0%	21.1%
Highway Sign	3	0	3	1	2	41	47	0.0%	6.4%	12.8%
Street light, Utility Pole	4	2	2	4	10	38	56	3.6%	7.1%	32.1%
Culvert	5	0	2	0	2	4	8	0.0%	25.0%	50.0%
Ditch,Embankment,Stream	6	0	4	2	16	74	96	0.0%	4.2%	22.9%
Bridge Pier or Abutment	7	0	0	0	1	1	2	0.0%	0.0%	0.0%
Bridge rail or deck	8	0	0	0	0	3	3	0.0%	0.0%	0.0%
Tree	9	1	5	2	4	32	44	2.3%	13.6%	27.3%
Highway or railroad signal	10	0	0	0	0	4	4	0.0%	0.0%	0.0%
Building	11	0	0	0	1	7	8	0.0%	0.0%	12.5%
Mailbox	12	0	1	0	2	29	32	0.0%	3.1%	9.4%
Fence	13	0	1	0	1	6	8	0.0%	12.5%	25.0%
Traffic island or curb	14	1	0	1	2	23	27	3.7%	3.7%	14.8%
Concrete median barrier	15	0	0	0	3	2	5	0.0%	0.0%	60.0%
Other on-trafficway object	16	0	0	0	5	43	48	0.0%	0.0%	10.4%
Other-off-trafficway object	17	0	1	1	2	14	18	0.0%	5.6%	22.2%
Overhead fixed object	18	0	0	0	0	3	3	0.0%	0.0%	0.0%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	4	7	1	20	5	37	10.8%	29.7%	86.5%
	TOTAL	12	44	28	125	816	1025	1.2%	5.5%	20.4%

MICHIGAN 1985-1991 FUNC_CLS = 17 = URBAN-COLLECTOR

Single-vehicle, Non-intersection/Non-interchange, Remove missing and errant values

OBJECT VEHICLE HIT	VEH_OBJ CODE#	SEVERITY					TOTAL	%(K)	%(K+A)	%(K+I)
		FATAL 1	INJURY LEVEL			PDO 5				
			A=2	B=3	C=4					
No object hit	1	3	6	1	9	157	176	1.7%	5.1%	10.8%
Guardrail or guard post	2	0	0	0	1	9	10	0.0%	0.0%	10.0%
Highway Sign	3	0	1	0	1	8	10	0.0%	10.0%	20.0%
Street light, Utility Pole	4	0	1	1	3	5	10	0.0%	10.0%	50.0%
Culvert	5	0	0	0	0	1	1	0.0%	0.0%	0.0%
Ditch,Embankment,Stream	6	0	1	0	4	12	17	0.0%	5.9%	29.4%
Bridge Pier or Abutment	7	0	0	0	0	0	0	0.0%	0.0%	0.0%
Bridge rail or deck	8	0	0	0	1	1	2	0.0%	0.0%	50.0%
Tree	9	2	2	0	2	4	10	20.0%	40.0%	60.0%
Highway or railroad signal	10	0	0	0	0	0	0	0.0%	0.0%	0.0%
Building	11	0	0	0	0	2	2	0.0%	0.0%	0.0%
Mailbox	12	0	0	0	0	3	3	0.0%	0.0%	0.0%
Fence	13	0	0	0	0	0	0	0.0%	0.0%	0.0%
Traffic island or curb	14	0	0	0	0	4	4	0.0%	0.0%	0.0%
Concrete median barrier	15	0	0	0	0	0	0	0.0%	0.0%	0.0%
Other on-trafficway object	16	0	1	0	0	8	9	0.0%	11.1%	11.1%
Other-off-trafficway object	17	0	0	0	0	2	2	0.0%	0.0%	0.0%
Overhead fixed object	18	0	0	0	0	0	0	0.0%	0.0%	0.0%
Not known or Non-motor-vehicle unit (pedestrian, etc.)	19	2	0	0	0	2	4	50.0%	50.0%	50.0%
	TOTAL	7	12	2	21	218	260	2.7%	7.3%	16.2%

APPENDIX B.
Gross Utah Accident Data by Functional Class

UTAH 1985-1992
Rural Interstate

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	13	101	85	57	473	729
Guardrail End	B	1	6	6	1	17	31
Utility Pole	C	0	5	3	4	36	48
Sign Post	D	11	39	30	17	212	309
Deliineator Post	E	54	319	212	112	751	1448
Bridge/Culvert	F	2	40	32	18	119	211
Curb	G	0	1	0	0	5	6
Safety Island	H	0	1	2	4	5	12
Fence	I	20	99	73	38	281	511
Rigid Concrete Barrier	J	6	43	40	41	238	368
Crash Cushion	K	0	0	0	1	8	9
Embankment	L	32	200	133	84	352	801
Wild Animal	M	0	1	2	0	9	12
Domestic Animal	N	0	0	1	0	0	1
Snow Bank	O	1	4	5	8	21	39
Mailbox	P	0	0	0	0	0	0
Channelizer	Q	1	3	3	1	13	21
Tree/Shrub	R	0	14	8	2	30	54
Building	S	0	0	2	1	9	12
Other Object	T	4	14	7	5	34	64
TOTAL	TOTAL	145	890	644	394	2613	4686

UTAH 1985-1992
Rural Major Collector

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	2	11	19	11	93	136
Guardrail End	B	0	1	2	1	5	9
Utility Pole	C	7	30	31	33	172	273
Sign Post	D	6	14	15	10	106	151
Deliineator Post	E	4	43	28	21	104	200
Bridge/Culvert	F	4	13	21	12	44	94
Curb	G	1	2	4	3	11	21
Safety Island	H	0	0	0	0	4	4
Fence	I	4	84	79	53	373	593
Rigid Concrete Barrier	J	0	5	8	5	21	39
Crash Cushion	K	0	0	0	0	0	0
Embankment	L	18	191	165	99	468	941
Wild Animal	M	0	0	2	1	3	6
Domestic Animal	N	0	0	1	1	2	4
Snow Bank	O	0	1	1	4	18	24
Mailbox	P	0	7	7	2	33	49
Channelizer	Q	0	5	1	1	3	10
Tree/Shrub	R	11	51	44	23	132	261
Building	S	0	4	10	0	21	35
Other Object	T	1	11	20	8	68	108
TOTAL	TOTAL	58	473	458	288	1681	2958

UTAH 1985-1992
Rural Minor Arterial

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	5	31	41	17	129	223
Guardrail End	B	1	0	0	1	3	5
Utility Pole	C	1	21	19	10	66	117
Sign Post	D	0	21	19	12	95	147
Deliineator Post	E	16	75	45	29	179	344
Bridge/Culvert	F	2	17	10	8	34	71
Curb	G	0	2	2	0	9	13
Safety Island	H	0	0	2	0	0	2
Fence	I	9	50	40	23	172	294
Rigid Concrete Barrier	J	2	13	13	4	49	81
Crash Cushion	K	0	1	0	0	2	3
Embankment	L	29	225	202	99	519	1074
Wild Animal	M	0	1	0	1	4	6
Domestic Animal	N	0	2	0	1	2	5
Snow Bank	O	0	5	6	8	50	69
Mailbox	P	0	0	0	2	2	4
Channelizer	Q	0	0	0	0	3	3
Tree/Shrub	R	4	33	32	29	111	209
Building	S	0	4	3	2	23	32
Other Object	T	4	20	11	5	53	93
TOTAL	TOTAL	73	521	445	251	1505	2795

UTAH 1985-1992
Rural Minor Collector

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	0	6	1	4	18	29
Guardrail End	B	0	1	0	1	0	2
Utility Pole	C	2	12	16	8	75	113
Sign Post	D	1	2	2	1	17	23
Deliineator Post	E	1	6	1	2	11	21
Bridge/Culvert	F	1	4	8	4	22	39
Curb	G	0	1	2	0	3	6
Safety Island	H	0	0	0	0	1	1
Fence	I	3	30	31	19	149	232
Rigid Concrete Barrier	J	0	5	1	0	8	14
Crash Cushion	K	0	0	0	0	1	1
Embankment	L	8	110	89	51	247	505
Wild Animal	M	0	0	0	0	0	0
Domestic Animal	N	0	0	0	0	1	1
Snow Bank	O	0	3	1	0	10	14
Mailbox	P	1	3	3	5	14	26
Channelizer	Q	0	0	0	0	1	1
Tree/Shrub	R	1	24	29	12	91	157
Building	S	0	2	2	2	11	17
Other Object	T	2	5	7	5	37	56
TOTAL	TOTAL	20	214	193	114	717	1258

UTAH 1985-1992
Rural Primary Arterial

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	4	29	38	21	197	289
Guardrail End	B	2	2	1	0	8	13
Utility Pole	C	0	11	18	10	74	113
Sign Post	D	3	8	14	10	67	102
Deliineator Post	E	8	42	39	30	164	283
Bridge/Culvert	F	3	18	12	8	49	90
Curb	G	0	1	3	3	14	21
Safety Island	H	0	0	0	1	4	5
Fence	I	6	31	31	26	160	254
Rigid Concrete Barrier	J	0	6	10	8	41	65
Crash Cushion	K	0	1	0	0	4	5
Embankment	L	18	134	126	82	307	667
Wild Animal	M	0	0	2	1	4	7
Domestic Animal	N	0	1	0	0	0	1
Snow Bank	O	0	2	3	5	26	36
Mailbox	P	0	3	1	0	8	12
Channelizer	Q	0	0	0	0	7	7
Tree/Shrub	R	4	15	24	11	57	111
Building	S	0	1	3	0	9	13
Other Object	T	2	2	9	3	34	50
TOTAL	TOTAL	50	307	334	219	1234	2144

UTAH 1985-1992
Rural Local

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	0	2	4	1	16	23
Guardrail End	B	0	0	0	0	1	1
Utility Pole	C	0	14	22	9	138	183
Sign Post	D	0	4	2	4	37	47
Deliineator Post	E	0	0	0	1	10	11
Bridge/Culvert	F	1	4	1	2	23	31
Curb	G	0	4	3	2	10	19
Safety Island	H	0	0	1	1	5	7
Fence	I	3	23	22	15	176	239
Rigid Concrete Barrier	J	0	4	2	0	6	12
Crash Cushion	K	0	0	1	0	0	1
Embankment	L	1	21	20	11	67	120
Wild Animal	M	0	0	0	0	0	0
Domestic Animal	N	0	0	0	0	0	0
Snow Bank	O	0	1	1	0	4	6
Mailbox	P	0	0	0	2	11	13
Channelizer	Q	0	0	0	0	0	0
Tree/Shrub	R	0	16	9	8	72	105
Building	S	0	4	7	3	195	209
Other Object	T	4	18	12	12	175	221
TOTAL	TOTAL	9	115	107	71	946	1248

UTAH 1985-1992
Urban Collector

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	1	8	7	8	34	58
Guardrail End	B	0	1	0	0	2	3
Utility Pole	C	4	88	93	87	400	672
Sign Post	D	1	16	10	9	142	178
Deliineator Post	E	0	2	2	3	10	17
Bridge/Culvert	F	2	15	11	10	44	82
Curb	G	3	34	25	25	170	257
Safety Island	H	0	2	3	4	14	23
Fence	I	0	25	33	37	355	450
Rigid Concrete Barrier	J	0	9	14	4	38	65
Crash Cushion	K	0	1	0	0	2	3
Embankment	L	0	28	35	15	119	197
Wild Animal	M	0	0	0	0	0	0
Domestic Animal	N	0	0	0	0	0	0
Snow Bank	O	0	1	0	0	3	4
Mailbox	P	0	4	4	5	63	76
Channelizer	Q	0	0	1	0	16	17
Tree/Shrub	R	0	38	45	22	142	247
Building	S	0	11	8	8	79	106
Other Object	T	1	31	21	15	139	207
TOTAL	TOTAL	12	314	312	252	1772	2662

UTAH 1985-1992
Urban Freeway

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	0	7	7	6	54	74
Guardrail End	B	0	0	0	0	1	1
Utility Pole	C	0	1	0	1	5	7
Sign Post	D	1	4	1	1	16	23
Deliineator Post	E	1	4	5	2	23	35
Bridge/Culvert	F	0	7	2	5	19	33
Curb	G	0	0	0	1	3	4
Safety Island	H	0	1	1	1	1	4
Fence	I	1	6	4	7	37	55
Rigid Concrete Barrier	J	1	6	1	3	11	22
Crash Cushion	K	0	3	0	0	7	10
Embankment	L	0	2	4	1	6	13
Wild Animal	M	0	0	0	0	0	0
Domestic Animal	N	0	0	0	0	0	0
Snow Bank	O	0	0	0	1	0	1
Mailbox	P	0	0	0	0	0	0
Channelizer	Q	0	1	0	1	4	6
Tree/Shrub	R	0	0	0	0	0	0
Building	S	0	0	0	0	2	2
Other Object	T	0	2	0	2	3	7
TOTAL	TOTAL	4	44	25	32	192	297

UTAH 1985-1992
Urban Interstate

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	10	123	145	145	847	1270
Guardrail End	B	0	9	4	6	29	48
Utility Pole	C	1	29	20	25	125	200
Sign Post	D	2	30	32	28	299	391
Deliineator Post	E	12	93	80	68	429	682
Bridge/Culvert	F	2	49	46	47	286	430
Curb	G	0	7	2	4	19	32
Safety Island	H	0	8	8	4	25	45
Fence	I	5	41	47	42	242	377
Rigid Concrete Barrier	J	5	103	109	117	611	945
Crash Cushion	K	0	6	5	5	26	42
Embankment	L	0	47	58	51	113	269
Wild Animal	M	0	0	0	0	1	1
Domestic Animal	N	0	0	0	0	0	0
Snow Bank	O	0	3	1	1	10	15
Mailbox	P	0	0	0	0	1	1
Channelizer	Q	0	0	1	3	15	19
Tree/Shrub	R	0	7	5	6	27	45
Building	S	1	0	1	0	11	13
Other Object	T	1	6	9	2	33	51
TOTAL	TOTAL	39	561	573	554	3149	4876

UTAH 1985-1992
Urban Local

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	2	14	4	9	38	67
Guardrail End	B	0	0	1	2	2	5
Utility Pole	C	3	58	85	42	334	522
Sign Post	D	0	10	9	6	122	147
Deliineator Post	E	0	0	0	0	3	3
Bridge/Culvert	F	1	12	5	3	52	73
Curb	G	3	27	21	15	129	195
Safety Island	H	0	2	1	3	12	18
Fence	I	0	49	33	39	473	594
Rigid Concrete Barrier	J	1	8	13	2	37	61
Crash Cushion	K	0	0	0	0	2	2
Embankment	L	1	31	33	23	90	178
Wild Animal	M	0	0	0	0	2	2
Domestic Animal	N	0	0	0	0	1	1
Snow Bank	O	0	0	1	1	4	6
Mailbox	P	0	4	6	2	52	64
Channelizer	Q	0	1	1	1	9	12
Tree/Shrub	R	1	56	40	25	180	302
Building	S	1	16	18	8	110	153
Other Object	T	1	35	40	26	312	414
TOTAL	TOTAL	14	323	311	207	1964	2819

UTAH 1985-1992
Urban Minor Arterial

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	1	22	17	23	82	145
Guardrail End	B	0	3	2	1	4	10
Utility Pole	C	12	145	145	113	566	981
Sign Post	D	0	20	30	27	224	301
Deliineator Post	E	1	4	3	2	36	46
Bridge/Culvert	F	1	23	22	13	80	139
Curb	G	2	33	27	27	209	298
Safety Island	H	1	10	13	7	35	66
Fence	I	3	36	43	33	339	454
Rigid Concrete Barrier	J	0	26	20	20	95	161
Crash Cushion	K	0	0	1	2	6	9
Embankment	L	4	30	41	24	171	270
Wild Animal	M	0	0	0	1	1	2
Domestic Animal	N	0	0	0	0	0	0
Snow Bank	O	0	3	2	1	12	18
Mailbox	P	1	4	7	9	71	92
Channelizer	Q	1	3	4	3	16	27
Tree/Shrub	R	2	45	39	20	126	232
Building	S	1	21	23	15	92	152
Other Object	T	2	28	30	25	185	270
TOTAL	TOTAL	32	456	469	366	2350	3673

UTAH 1985-1992
Urban Primary Arterial

Object Struck	OBJ_STRK	K=5	A=4	B=3	C=2	PDO=1	Total
Guardrail	A	0	17	18	16	108	159
Guardrail End	B	0	1	2	1	4	8
Utility Pole	C	2	91	69	53	299	514
Sign Post	D	2	21	17	14	158	212
Deliineator Post	E	2	4	12	3	25	46
Bridge/Culvert	F	1	11	12	5	33	62
Curb	G	2	21	27	12	102	164
Safety Island	H	0	5	6	8	24	43
Fence	I	2	23	31	21	198	275
Rigid Concrete Barrier	J	0	13	23	16	98	150
Crash Cushion	K	0	2	2	2	11	17
Embankment	L	3	24	37	31	94	189
Wild Animal	M	0	0	1	0	0	1
Domestic Animal	N	0	0	0	0	0	0
Snow Bank	O	0	0	7	1	8	16
Mailbox	P	0	6	5	3	33	47
Channelizer	Q	0	1	2	0	13	16
Tree/Shrub	R	5	26	24	16	86	157
Building	S	0	17	10	4	82	113
Other Object	T	1	3	11	6	65	86
TOTAL	TOTAL	20	286	316	212	1441	2275

APPENDIX C.
Embankment Severities classified by Depth.

ACTUAL EMBANKMENT SEVERITIES THAT WERE ADJUSTED BY EMBANKMENT DEPTH (FROM B/C PROGRAM)

Embankment	Embankment Height		Embankment Width		B/C	IMPACT SPEED(mph)						IMPACT SPEED(kph)							
Slope	D(ft)	D(m)	W(ft)	W(m)	SI/mph	30	40	50	60	70	80	50	60	70	80	90	100	110	120
1.0:1	1.0	0.3	1.0	0.3	.0557	1.7	2.2	2.8	3.3	3.9	4.5	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2
1.0:1	2.0	0.6	2.0	0.6	.0686	2.1	2.7	3.4	4.1	4.8	5.5	2.1	2.6	3.0	3.4	3.9	4.3	4.7	5.1
1.0:1	3.0	0.9	3.0	0.9	.0786	2.4	3.1	3.9	4.7	5.5	6.3	2.5	2.9	3.4	3.9	4.4	4.9	5.4	5.9
1.0:1	4.0	1.2	4.0	1.2	.0843	2.5	3.4	4.2	5.1	5.9	6.7	2.6	3.2	3.7	4.2	4.7	5.3	5.8	6.3
1.0:1	5.0	1.5	5.0	1.5	.0900	2.7	3.6	4.5	5.4	6.3	7.2	2.8	3.4	3.9	4.5	5.1	5.6	6.2	6.8
1.0:1	6.0	1.8	6.0	1.8	.0937	2.8	3.7	4.7	5.6	6.6	7.5	2.9	3.5	4.1	4.7	5.3	5.9	6.4	7.0
1.0:1	10.0	3.0	10.0	3.0	.1021	3.1	4.1	5.1	6.1	7.2	8.2	3.2	3.8	4.5	5.1	5.7	6.4	7.0	7.7
1.0:1	14.0	4.3	14.0	4.3	.1051	3.2	4.2	5.3	6.3	7.4	8.4	3.3	3.9	4.6	5.3	5.9	6.6	7.2	7.9
1.0:1	18.0	5.5	18.0	5.5	.1064	3.2	4.3	5.3	6.4	7.4	8.5	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0
1.0:1	22.0	6.7	22.0	6.7	.1071	3.2	4.3	5.4	6.4	7.5	8.6	3.3	4.0	4.7	5.4	6.0	6.7	7.4	8.0
1.5:1	1.0	0.3	1.5	0.5	.0471	1.4	1.9	2.4	2.8	3.3	3.8	1.5	1.8	2.1	2.4	2.7	2.9	3.2	3.5
1.5:1	2.0	0.6	3.0	0.9	.0614	1.8	2.5	3.1	3.7	4.3	4.9	1.9	2.3	2.7	3.1	3.5	3.8	4.2	4.6
1.5:1	3.0	0.9	4.5	1.4	.0700	2.1	2.8	3.5	4.2	4.9	5.6	2.2	2.6	3.1	3.5	3.9	4.4	4.8	5.3
1.5:1	4.0	1.2	6.0	1.8	.0750	2.3	3.0	3.8	4.5	5.3	6.0	2.3	2.8	3.3	3.8	4.2	4.7	5.2	5.6
1.5:1	5.0	1.5	7.5	2.3	.0800	2.4	3.2	4.0	4.8	5.6	6.4	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
1.5:1	6.0	1.8	9.0	2.7	.0837	2.5	3.3	4.2	5.0	5.9	6.7	2.6	3.1	3.7	4.2	4.7	5.2	5.8	6.3
1.5:1	10.0	3.0	15.0	4.6	.0907	2.7	3.6	4.5	5.4	6.3	7.3	2.8	3.4	4.0	4.5	5.1	5.7	6.2	6.8
1.5:1	14.0	4.3	21.0	6.4	.0933	2.8	3.7	4.7	5.6	6.5	7.5	2.9	3.5	4.1	4.7	5.2	5.8	6.4	7.0
1.5:1	18.0	5.5	27.0	8.2	.0943	2.8	3.8	4.7	5.7	6.6	7.5	2.9	3.5	4.1	4.7	5.3	5.9	6.5	7.1
1.5:1	22.0	6.7	33.0	10.1	.0943	2.8	3.8	4.7	5.7	6.6	7.5	2.9	3.5	4.1	4.7	5.3	5.9	6.5	7.1
2.0:1	1.0	0.3	2.0	0.6	.0421	1.3	1.7	2.1	2.5	3.0	3.4	1.3	1.6	1.8	2.1	2.4	2.6	2.9	3.2
2.0:1	2.0	0.6	4.0	1.2	.0540	1.6	2.2	2.7	3.2	3.8	4.3	1.7	2.0	2.4	2.7	3.0	3.4	3.7	4.1
2.0:1	3.0	0.9	6.0	1.8	.0614	1.8	2.5	3.1	3.7	4.3	4.9	1.9	2.3	2.7	3.1	3.5	3.8	4.2	4.6
2.0:1	4.0	1.2	8.0	2.4	.0664	2.0	2.7	3.3	4.0	4.7	5.3	2.1	2.5	2.9	3.3	3.7	4.2	4.6	5.0
2.0:1	5.0	1.5	10.0	3.0	.0714	2.1	2.9	3.6	4.3	5.0	5.7	2.2	2.7	3.1	3.6	4.0	4.5	4.9	5.4
2.0:1	6.0	1.8	12.0	3.7	.0743	2.2	3.0	3.7	4.5	5.2	5.9	2.3	2.8	3.2	3.7	4.2	4.6	5.1	5.6
2.0:1	10.0	3.0	20.0	6.1	.0814	2.4	3.3	4.1	4.9	5.7	6.5	2.5	3.1	3.6	4.1	4.6	5.1	5.6	6.1
2.0:1	14.0	4.3	28.0	8.5	.0826	2.5	3.3	4.1	5.0	5.8	6.6	2.6	3.1	3.6	4.1	4.6	5.2	5.7	6.2
2.0:1	18.0	5.5	36.0	11.0	.0830	2.5	3.3	4.1	5.0	5.8	6.6	2.6	3.1	3.6	4.1	4.7	5.2	5.7	6.2
2.0:1	22.0	6.7	44.0	13.4	.0830	2.5	3.3	4.1	5.0	5.8	6.6	2.6	3.1	3.6	4.1	4.7	5.2	5.7	6.2
2.5:1	1.0	0.3	2.5	0.8	.0350	1.0	1.4	1.8	2.1	2.5	2.8	1.1	1.3	1.5	1.8	2.0	2.2	2.4	2.6
2.5:1	2.0	0.6	5.0	1.5	.0457	1.4	1.8	2.3	2.7	3.2	3.7	1.4	1.7	2.0	2.3	2.6	2.9	3.1	3.4
2.5:1	3.0	0.9	7.5	2.3	.0529	1.6	2.1	2.6	3.2	3.7	4.2	1.7	2.0	2.3	2.6	3.0	3.3	3.6	4.0
2.5:1	4.0	1.2	10.0	3.0	.0571	1.7	2.3	2.9	3.4	4.0	4.6	1.8	2.1	2.5	2.9	3.2	3.6	3.9	4.3
2.5:1	5.0	1.5	12.5	3.8	.0614	1.8	2.5	3.1	3.7	4.3	4.9	1.9	2.3	2.7	3.1	3.5	3.8	4.2	4.6
2.5:1	6.0	1.8	15.0	4.6	.0645	1.9	2.6	3.2	3.9	4.5	5.2	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8
2.5:1	10.0	3.0	25.0	7.6	.0707	2.1	2.8	3.5	4.2	4.9	5.7	2.2	2.7	3.1	3.5	4.0	4.4	4.9	5.3
2.5:1	14.0	4.3	35.0	10.7	.0714	2.1	2.9	3.6	4.3	5.0	5.7	2.2	2.7	3.1	3.6	4.0	4.5	4.9	5.4
2.5:1	18.0	5.5	45.0	13.7	.0714	2.1	2.9	3.6	4.3	5.0	5.7	2.2	2.7	3.1	3.6	4.0	4.5	4.9	5.4
2.5:1	22.0	6.7	55.0	16.8	.0714	2.1	2.9	3.6	4.3	5.0	5.7	2.2	2.7	3.1	3.6	4.0	4.5	4.9	5.4
3.0:1	1.0	0.3	3.0	0.9	.0271	0.8	1.1	1.4	1.6	1.9	2.2	0.8	1.0	1.2	1.4	1.5	1.7	1.9	2.0
3.0:1	2.0	0.6	6.0	1.8	.0371	1.1	1.5	1.9	2.2	2.6	3.0	1.2	1.4	1.6	1.9	2.1	2.3	2.6	2.8
3.0:1	3.0	0.9	9.0	2.7	.0443	1.3	1.8	2.2	2.7	3.1	3.5	1.4	1.7	1.9	2.2	2.5	2.8	3.0	3.3
3.0:1	4.0	1.2	12.0	3.7	.0486	1.5	1.9	2.4	2.9	3.4	3.9	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6
3.0:1	5.0	1.5	15.0	4.6	.0529	1.6	2.1	2.6	3.2	3.7	4.2	1.7	2.0	2.3	2.6	3.0	3.3	3.6	4.0
3.0:1	6.0	1.8	18.0	5.5	.0551	1.7	2.2	2.8	3.3	3.9	4.4	1.7	2.1	2.4	2.8	3.1	3.4	3.8	4.1
3.0:1	10.0	3.0	30.0	9.1	.0593	1.8	2.4	3.0	3.6	4.2	4.7	1.9	2.2	2.6	3.0	3.3	3.7	4.1	4.4
3.0:1	14.0	4.3	42.0	12.8	.0594	1.8	2.4	3.0	3.6	4.2	4.8	1.9	2.2	2.6	3.0	3.3	3.7	4.1	4.5
3.0:1	18.0	5.5	54.0	16.5	.0594	1.8	2.4	3.0	3.6	4.2	4.8	1.9	2.2	2.6	3.0	3.3	3.7	4.1	4.5
3.0:1	22.0	6.7	66.0	20.1	.0594	1.8	2.4	3.0	3.6	4.2	4.8	1.9	2.2	2.6	3.0	3.3	3.7	4.1	4.5

ACTUAL EMBANKMENT SEVERITIES THAT WERE ADJUSTED BY EMBANKMENT DEPTH (FROM B/C PROGRAM)

Embankment	Embankment Height		Embankment Width		B/C	IMPACT SPEED(mph)						IMPACT SPEED(kph)							
Slope	D(ft)	D(m)	W(ft)	W(m)	SI/mph	30	40	50	60	70	80	50	60	70	80	90	100	110	120
3.5:1	1.0	0.3	3.5	1.1	.0221	0.7	0.9	1.1	1.3	1.5	1.8	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.7
3.5:1	2.0	0.6	7.0	2.1	.0314	0.9	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
3.5:1	3.0	0.9	10.5	3.2	.0371	1.1	1.5	1.9	2.2	2.6	3.0	1.2	1.4	1.6	1.9	2.1	2.3	2.6	2.8
3.5:1	4.0	1.2	14.0	4.3	.0407	1.2	1.6	2.0	2.4	2.8	3.3	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.1
3.5:1	5.0	1.5	17.5	5.3	.0443	1.3	1.8	2.2	2.7	3.1	3.5	1.4	1.7	1.9	2.2	2.5	2.8	3.0	3.3
3.5:1	6.0	1.8	21.0	6.4	.0455	1.4	1.8	2.3	2.7	3.2	3.6	1.4	1.7	2.0	2.3	2.6	2.8	3.1	3.4
3.5:1	10.0	3.0	35.0	10.7	.0476	1.4	1.9	2.4	2.9	3.3	3.8	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6
3.5:1	14.0	4.3	49.0	14.9	.0476	1.4	1.9	2.4	2.9	3.3	3.8	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6
3.5:1	18.0	5.5	63.0	19.2	.0476	1.4	1.9	2.4	2.9	3.3	3.8	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6
3.5:1	22.0	6.7	77.0	23.5	.0476	1.4	1.9	2.4	2.9	3.3	3.8	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6
4.0:1	1.0	0.3	4.0	1.2	.0186	0.6	0.7	0.9	1.1	1.3	1.5	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.4
4.0:1	2.0	0.6	8.0	2.4	.0264	0.8	1.1	1.3	1.6	1.9	2.1	0.8	1.0	1.2	1.3	1.5	1.7	1.8	2.0
4.0:1	3.0	0.9	12.0	3.7	.0314	0.9	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
4.0:1	4.0	1.2	16.0	4.9	.0344	1.0	1.4	1.7	2.1	2.4	2.8	1.1	1.3	1.5	1.7	1.9	2.2	2.4	2.6
4.0:1	5.0	1.5	20.0	6.1	.0374	1.1	1.5	1.9	2.2	2.6	3.0	1.2	1.4	1.6	1.9	2.1	2.3	2.6	2.8
4.0:1	6.0	1.8	24.0	7.3	.0384	1.2	1.5	1.9	2.3	2.7	3.1	1.2	1.4	1.7	1.9	2.2	2.4	2.6	2.9
4.0:1	10.0	3.0	40.0	12.2	.0391	1.2	1.6	2.0	2.3	2.7	3.1	1.2	1.5	1.7	2.0	2.2	2.4	2.7	2.9
4.0:1	14.0	4.3	56.0	17.1	.0391	1.2	1.6	2.0	2.3	2.7	3.1	1.2	1.5	1.7	2.0	2.2	2.4	2.7	2.9
4.0:1	18.0	5.5	72.0	21.9	.0391	1.2	1.6	2.0	2.3	2.7	3.1	1.2	1.5	1.7	2.0	2.2	2.4	2.7	2.9
4.0:1	22.0	6.7	88.0	26.8	.0391	1.2	1.6	2.0	2.3	2.7	3.1	1.2	1.5	1.7	2.0	2.2	2.4	2.7	2.9
4.5:1	1.0	0.3	4.5	1.4	.0157	0.5	0.6	0.8	0.9	1.1	1.3	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
4.5:1	2.0	0.6	9.0	2.7	.0229	0.7	0.9	1.1	1.4	1.6	1.8	0.7	0.9	1.0	1.1	1.3	1.4	1.6	1.7
4.5:1	3.0	0.9	13.5	4.1	.0271	0.8	1.1	1.4	1.6	1.9	2.2	0.8	1.0	1.2	1.4	1.5	1.7	1.9	2.0
4.5:1	4.0	1.2	18.0	5.5	.0293	0.9	1.2	1.5	1.8	2.0	2.3	0.9	1.1	1.3	1.5	1.6	1.8	2.0	2.2
4.5:1	5.0	1.5	22.5	6.9	.0314	0.9	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
4.5:1	6.0	1.8	27.0	8.2	.0317	1.0	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
4.5:1	10.0	3.0	45.0	13.7	.0317	1.0	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
4.5:1	14.0	4.3	63.0	19.2	.0317	1.0	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
4.5:1	18.0	5.5	81.0	24.7	.0317	1.0	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
4.5:1	22.0	6.7	99.0	30.2	.0317	1.0	1.3	1.6	1.9	2.2	2.5	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
5.0:1	1.0	0.3	5.0	1.5	.0114	0.3	0.5	0.6	0.7	0.8	0.9	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9
5.0:1	2.0	0.6	10.0	3.0	.0186	0.6	0.7	0.9	1.1	1.3	1.5	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.4
5.0:1	3.0	0.9	15.0	4.6	.0229	0.7	0.9	1.1	1.4	1.6	1.8	0.7	0.9	1.0	1.1	1.3	1.4	1.6	1.7
5.0:1	4.0	1.2	20.0	6.1	.0243	0.7	1.0	1.2	1.5	1.7	1.9	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
5.0:1	5.0	1.5	25.0	7.6	.0243	0.7	1.0	1.2	1.5	1.7	1.9	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
5.0:1	6.0	1.8	30.0	9.1	.0243	0.7	1.0	1.2	1.5	1.7	1.9	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
5.0:1	10.0	3.0	50.0	15.2	.0243	0.7	1.0	1.2	1.5	1.7	1.9	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
5.0:1	14.0	4.3	70.0	21.3	.0243	0.7	1.0	1.2	1.5	1.7	1.9	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
5.0:1	18.0	5.5	90.0	27.4	.0243	0.7	1.0	1.2	1.5	1.7	1.9	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
5.0:1	22.0	6.7	110.0	33.5	.0243	0.7	1.0	1.2	1.5	1.7	1.9	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8