

A STUDY OF ACCIDENTS INVOLVING HIGHWAY BRIDGES

by

M. H. Hilton  
Highway Research Engineer  
and  
J. R. Redick  
Graduate Student Assistant

Virginia Highway Research Council  
(A Cooperative Organization Sponsored Jointly by the Virginia  
Department of Highways and the University of Virginia)

Charlottesville, Virginia

March 1971  
VHRC 70-R34



## SUMMARY

Accident reports, field evaluations, state police and highway engineer questionnaire replies, and other data sources were used to conduct a general study of accidents involving highway bridges in Virginia. The bridges included in the study were divided into three groups. These were: (a) Arterial and primary system bridges, (b) interstate system bridges, and (c) draw and swing span bridges.

Several geometric type characteristics were found to predominate at many of the arterial and primary system bridges investigated. On interstate bridges poor surface conditions were found to prevail during a significantly high number of accidents, and rear end collisions proved to be a significant problem on several toll draw or swing span structures. A more detailed listing of these and other findings are summarized under the conclusions of the report.

The upgrading of existing bridge rail-approach guardrail systems, widening of certain narrow roadway width bridges, and certain precautionary considerations for use during planning and design are among a number of recommendations offered at the end of the report.



## A STUDY OF ACCIDENTS INVOLVING HIGHWAY BRIDGES

by

M. H. Hilton  
Highway Research Engineer  
and  
J. R. Redick  
Graduate Student Assistant

## INTRODUCTION

Highway accidents can be divided into a number of categories such as "head on", "fixed object", "pedestrian", etc., by nature of the collision involved. Accidents which can be included in the general fixed object category accounted for a substantial proportion of the total accidents occurring on the Virginia interstate, arterial and primary systems during the period 1966 - 1969 (Table I). Furthermore, accidents involving fixed objects are generally more severe than those in other categories as indicated by the consistently higher proportion of deaths as compared to the proportion of accidents. Based on an average over the four-year period (1966 - 1969), 25.1% of the accidents were of the fixed object type whereas 30.9% of the deaths were associated with this type accident.

TABLE I\*

COMPARISON OF FIXED OBJECT AND TOTAL ACCIDENT  
STATISTICS FOR THE VIRGINIA INTERSTATE, ARTERIAL  
AND PRIMARY HIGHWAY SYSTEMS, 1966-1969(1,2,3,4)

Year	Fixed Object Accidents			All Accidents			% of all Acc.	% of all Acc. Deaths
	Accid.	Killed	Injured	Accid.	Killed	Injured		
	No.	No.	No.	No.	No.	No.		
1966	8,347	197	4,079	34,502	665	15,958	24.2%	29.6%
1967	8,408	215	4,102	33,870	736	16,317	24.8%	29.2%
1968	9,182	226	4,578	36,802	726	17,532	24.9%	31.1%
1969	10,755	255	—	40,816	760	—	26.3%	33.6%
Average							25.1%	30.9%

\*Excludes accidents occurring on the Virginia secondary highway system.

Many of the factors contributing to the cause or severity of fixed object accidents are beyond the control of highway engineers and administrators. In a study of single vehicle accidents, for example, Baker<sup>(5)</sup> reported that driver related contributing factors were associated with 44.5% of the accidents; vehicle contributing factors, 19.9%; and road factors, 18.3%. The significance of this type information lies not in the fact that roadway factors contribute the least toward accidents, but that human errors, mechanical failures, and adverse environmental conditions are virtually inevitable. Recognizing these realities, the highway engineer can contribute toward reducing the severity of many accidents resulting from basic causes other than the roadway itself. Accordingly, the fixed object accident has emerged as an area where significant contributions to highway safety can be made through design innovations and correction of obsolescent roadways.

One of the most formidable of the various types of fixed objects is the highway bridge structure. The general severity of collisions associated with bridge structures on Virginia's interstate, arterial, and primary systems is indicated from the data presented in Table II. By expressing accident severity for any given year and type of highway system (or systems) in the form of a Severity Index (SI) the data from Tables I and II can be illustrated more vividly. Thus, for any general type of accident, if we define

$$SI = \frac{D_p}{A_p}$$

where,

SI = Severity Index,

$D_p$  = Proportion of persons killed (percent),

$A_p$  = Proportion of all accidents (percent),

the relative severity of accidents involving highway bridges becomes more apparent as shown in Figure 1. In this figure the average severity of all accidents of all types on any given highway system would have a SI of unity. Comparatively, then, general fixed object accidents are more severe than average; and accidents involving bridges are roughly twice as severe as the average accident over the four-year period illustrated.

To combat the severity of accidents involving structures recent Virginia bridge designs have incorporated the "General Motors" type safety parapet wall<sup>(6)</sup> with the approach roadway guardrail anchored to the face of the wall at each end of the structure, and the full roadway shoulder width is now carried across new bridges whenever it is

feasible to do so. An electronically controlled ice warning device<sup>(7)</sup> has been installed at one hazardous bridge location<sup>(8)</sup> and similar installations are scheduled for nineteen other bridges on the interstate system. In concert with this progress the present study was undertaken in an effort to identify some of the factors which might contribute to accidents involving highway bridges.

TABLE II  
ACCIDENTS INVOLVING BRIDGES ON VIRGINIA'S  
INTERSTATE, ARTERIAL AND PRIMARY  
HIGHWAY SYSTEMS\*

Year	Interstate Highways		Arterial and Primary Highways	
	Proportion of all Accidents, Percent	Proportion of all Persons Killed, Percent	Proportion of all Accidents, Percent	Proportion of all Persons Killed, Percent
1966	3.7	7.3	1.8	3.9
1967	3.2	6.8	1.5	2.9
1968	2.7	5.1	1.4	3.7
1969	3.1	9.0	1.5	3.0
Average	3.2	7.1	1.6	3.4

\*Data developed from statistics obtained from References (1), (2), (3) and (4).

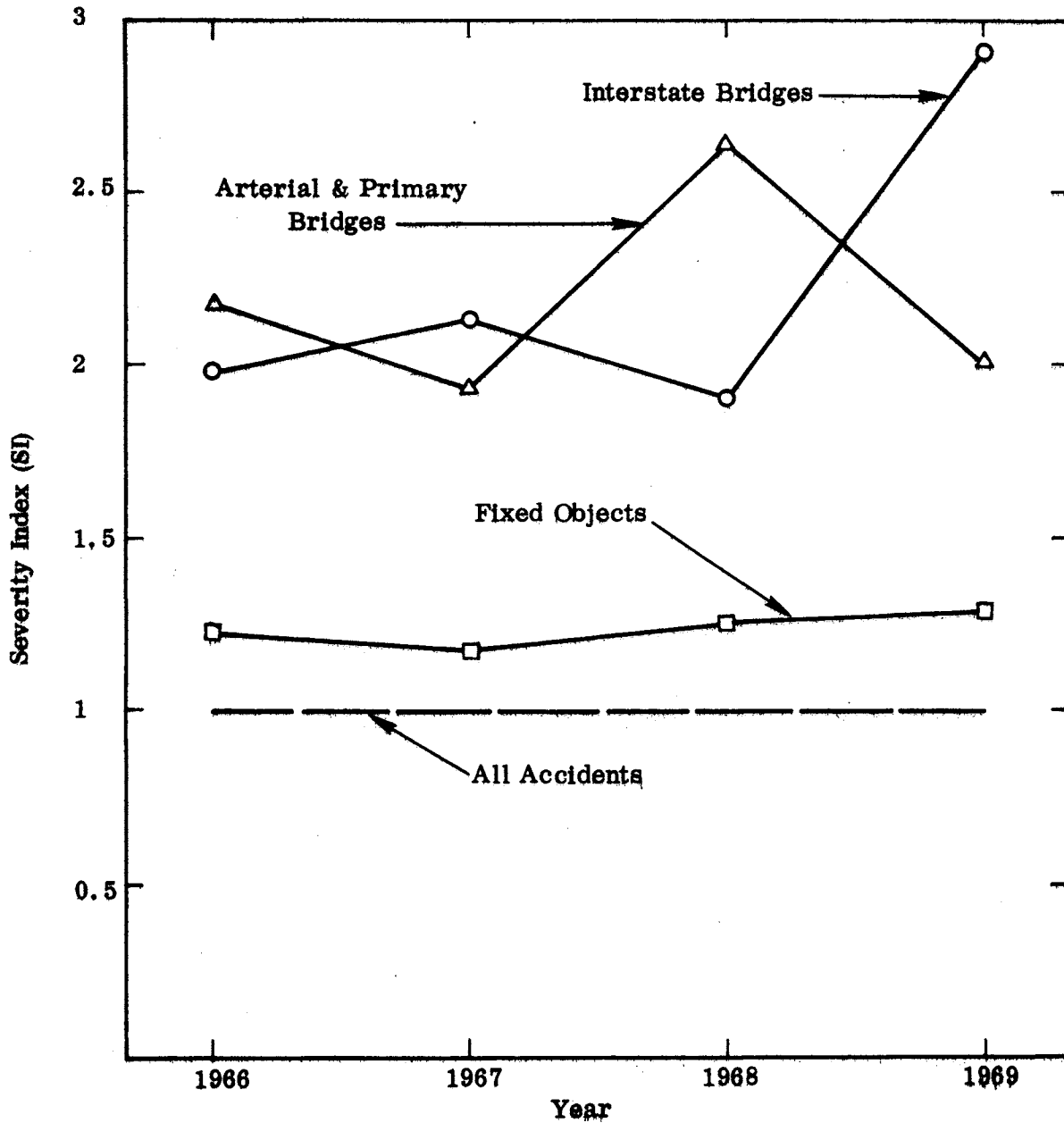


Figure 1. Relative severity of accidents involving bridge structures and fixed objects.



## PURPOSE AND SCOPE

Recognizing that "accidents occur as a result of a complex combination of a variety of factors", the Research Section of the Highway Safety Action Program<sup>(9)</sup> calls for research to assist in the identification of conditions which tend to be associated with accidents. In addition, the Engineering Section of the Program<sup>(10)</sup> calls for more specific attention to be given to relating the frequency of accidents to engineering features. As an effort in these two areas, and with respect to highway bridges, the general purposes of this study were:

1. To evaluate the usefulness of Virginia's standard accident report information for studying accidents involving specific roadway structures such as bridges;
2. to identify some of the bridge sites in Virginia which have been involved in accidents, and to study these structures and their approach conditions to determine the frequency of occurrence of common geometrical and design characteristics;
3. to identify some of the general geometrical, design, and physical factors which appear to contribute to accident frequency and/or severity at highway bridge sites, and
4. to evaluate the general need for certain safety improvements at some of the existing (and perhaps future) bridge sites in Virginia.

The scope of the study was limited to accidents at bridge sites on the interstate, arterial, and primary highway systems. The accidents studied were limited primarily to those which were reported during 1966. In some instances, as will be noted where applicable, data for years other than 1966 were used.

The scope of the study precludes the likelihood that all of the most accident prone bridge locations would be identified. On a state-wide basis, however, incorporating all the accidents involving bridges during 1966 plus the use of other data sources as listed below should reveal features typical of many potentially hazardous bridge sites.

The following data sources were used in the study.

1. The standard form (SR300) accident reports which are processed through the Virginia Department of Highways Traffic and Safety Division.
2. Questionnaire replies submitted by the six Virginia State Police divisions.
3. Questionnaire replies submitted by the Virginia Department of Highways district offices.
4. Engineering and geometric data obtained from the original roadway plans for a select group of interstate highway bridge sites involved in accidents during 1966.
5. General physical and geometric data obtained from field inspections of a number of arterial and primary system bridge sites randomly selected from a list of bridges compiled from data sources 1, 2, and 3 above.

The information from each accident report was reduced to a more compact form which included a description of the accident, its location, and environmental, driver, roadway, and vehicle conditions. From these data a number of bridge sites were revealed which had several accidents during 1966. For those sites that appeared to have an unusually high number of accidents, accident reports for years other than 1966 were reviewed.

In order to utilize the experiences of state police officers and the district highway field engineers, questionnaires were mailed to each of the six state police divisions and eight highway districts. The same questionnaires, which were limited to two general but broad requests, were mailed to each organization. The first request asked the respondent to list those bridges in his area which, in his view, had been the scene of more than a normal number of accidents, and to provide any information possible regarding those sites listed. The second request solicited any general remarks or suggestions that the respondent wished to make regarding hazardous conditions at bridge sites. The results from these two groups of questionnaires were summarized and incorporated in the study.

Using the information from the accident reports and the questionnaire replies a list of bridge sites was compiled, and thirty arterial and primary system bridges were randomly selected for field inspection.

Since interstate highways carry controlled access traffic and the bridges have generally been constructed to relatively high design standards, these structures were separated from those on the arterial and primary systems. For a select group of the interstate bridges (those involved in more than two accidents during 1966), engineering and geometric data were obtained from the original roadway plans for study.

The draw and swing span type structures were also reviewed separately since such factors as traffic delays due to toll collections or span openings and unique physical characteristics, rendered this group distinctly different from the more typical highway bridges.

## RESULTS

### Accident Report and Questionnaire Evaluation

#### Evaluation of Accident Report Data

It was not known at the outset of the study how useful the standard accident report information would be for studying accidents involving bridges. Consequently, one of the objectives of the study was to evaluate the report as a data source, and to offer suggestions which might enhance its value in any future study of specific roadway features.

The Virginia accident report supplies a basic description of the location of an accident and can be used to designate by means of a check list such factors as the weather, light, driver, vehicle, alignment and road surface conditions. The weaknesses of check list systems have been noted by Garrett and Tharp,<sup>(11)</sup> who point out that such systems are often not satisfactory for describing the actual conditions at the scene of an accident. Furthermore, even the information recorded may be ambiguous or misleading to an analyst attempting to make use of the data. On the other hand, the Virginia report form is used by anyone reporting an accident whether it be an investigating officer or an individual involved in the accident. For general usage of this type, the report should not be too complex or confusing -- so improving its format would not be a simple matter. It is likely that the present form has served to supply much information that otherwise would have gone unreported. Garrett and Tharp concluded from their work, however, that typical accident reports must be used with caution since the majority are completed by the most biased reporter -- the driver. They further concluded that the data collection forms and procedures do not meet research requirements and the reporting is not complete. Experience from the present study has not indicated an exception to these general conclusions.

To be of maximum value to roadway research and design accident data should be relatable to physical and geometric parameters. The section of the Virginia report best suited to supply much of this type of quantitative data appears to be the diagram and description of the accident. The quantity and quality of the information currently supplied in this section varies -- some diagrams are very good, others are rough or incomplete, and some are omitted entirely. While reports completed by the state police officers are usually superior to those completed by investigating officers of other agencies and by involved individuals, seldom is quantitative data -- whether approximate or exact -- supplied by either.

For general studies such as the present one, the typical accident report supplies useful information, but this must be supplemented by data obtained by other means. For more specific research objectives accident records more detailed than those currently available would be necessary. It is therefore suggested that for possible future studies of roadway structures the additional accident information listed in Appendix A be obtained whenever possible.

It would be impractical to complete all accident reports in such a manner as to maximize their usefulness to research. Since analysis of a limited sampling of accident data has been recognized<sup>(11,12)</sup> as sufficient for most research purposes, the extra data suggested in Appendix A should be collected only for special studies of accidents involving highway structures. The geographic area of coverage could also be limited to one or two state police divisions. In this manner accident investigation procedures and techniques, and supplemental data collection and analysis, could be more efficiently coordinated. While some of the additional accident information suggested could be routinely recorded without much additional effort, it was not a purpose of this study to recommend changes in current general practices. If changes are considered, however, additional data such as that suggested would enhance the value of accident reports for roadway research purposes.

#### Evaluation of Questionnaire Replies

Virginia is divided into six state police divisions and replies to the questionnaires described earlier were received from each division. A total of 69 bridge sites were listed by the state police as being hazardous locations. Comments regarding the factors which the officers felt contributed to hazardous conditions were made on all the sites listed. Only four of the sites were interstate bridges with one being the Route 495 Woodrow Wilson draw bridge over the Potomac River. (Note, however, that a number of interstate bridges have been constructed subsequent to this study, and, consequently, are not included.) All the remaining sites are on the primary system, and three of these are major toll facility draw or swing span type structures. Since the toll structures represent a unique situation, police comments on these facilities will be included later in the report.

Seven of the eight highway districts submitted replies to the inquiry but only six districts listed specific structures as requested. A total of 79 bridge sites were designated and specific comments were made on 50, (63%) of the sites. While some sites were identical to those designated by the state police, most were different. The vast majority were on the primary system, and none of the toll facilities were listed since these structures are not under the jurisdiction of the district highway offices.

Table III summarizes the factors which the police officers and engineers mentioned most frequently as contributing to accidents at certain bridge locations. The three most frequently mentioned contributing factors were: (a) Bridge roadway too narrow, (b) curved approach roadway alignment, and (c) curved bridge alignment. It is interesting to note that the order of these three factors in Table III is the same for each reporting group. Nearly half the bridges commented upon by each group were felt to have inadequate roadway width. Curved approach and curved bridge alignment were cited as factors contributing to hazardous conditions at 20% to 28% of the sites commented upon. The combined effects of restricted bridge roadway width and curved approach roadway alignment or curved bridge alignment were cited in approximately half the cases where curvature was considered a contributing factor. Other factors of accord between the two groups were downhill approach and inadequate vertical clearance conditions, which were mentioned in 4% to 12% of the cases cited.

TABLE III  
FACTORS CONTRIBUTING TO ACCIDENTS AT BRIDGE SITES  
(Summarized from State Police and Highway Engineer Questionnaire Replies)

Type of Contributing Factor	State Police Officers		Highway Engineers	
	No. of bridges	% of total bridges cited	No. of bridges	% of total bridges cited**
Bridge roadway too narrow*	32	46	24	48
Curved approach roadway*	19	28	11	22
Bridge curved*	16	23	10	20
Intersection adjacent to bridge	8	12	1	2
Approach lane drop and transitions at bridge	6	9	1	2
Downhill approach*	5	7	6	12
Snow and Ice	5	7	—	—
Slippery when wet	4	6	—	—
Inadequate vertical clearance	3	4	3	6
Insufficient curve elevation	2	3	1	2
Rough approach & rough bridge	2	3	—	—
Pedestrian <sup>b</sup> crossing narrow bridge	2	3	—	—

\*The combined effects of these factors were frequently cited.

\*\*The percentage of bridges is based on 50 sites which were commented on from a total of 79 sites listed by highway engineers.

More subtle factors such as approach roadway lane drops and transitions, intersections adjacent to bridges, and snow and ice problems on bridge decks were cited much more frequently by police officers than by highway engineers. Approach roadway lane reductions and transitions at the entrances to some bridges were felt to contribute to the likelihood that fixed objects (bridge and guard rail, etc.) would be involved in accidents. Intersections and interchange ramp connections adjacent to bridges were also cited as constituting a hazard since the bridge railings obstruct vision and entering and turning traffic increase the possibility of accidents involving collisions with the structure. Although the results summarized in Table III are subjective in nature, substantial support from the work of others (13, 14, 15, 16, 17) exists and will be discussed in more detail later.

A general comparison of the two groups of questionnaire replies revealed several facts which might be expected but, nonetheless, are worthy of mention. First, actual on-the-scene accident investigation is one of the regular duties of police officers. Consequently, because of their experience, they appear more likely than most highway engineers to recognize roadway factors which might contribute to accident frequency and/or severity. Secondly, the replying engineers recognized and reported many of the bridge sites which have had abnormally high numbers of accidents; but some engineers appeared more inclined than the police officers to accept driver errors as the basic cause of most accidents.

The results of the questionnaire portion of the study indicate that when state police officers are queried about specific highway features, such as bridge sites, they often can direct attention to factors and trouble areas which otherwise would go unnoticed. It might be concluded that periodic formal meetings of limited scope between design engineers and the state police officers might help to define areas where new design criteria would be beneficial to roadway safety.

### Field Inspections and Evaluations

#### Arterial and Primary System Bridges

From the 1966 accident reports, 554 accidents occurring at arterial and primary system bridge sites were reviewed. Along with the questionnaire replies, the accident reports were used to compile a list of accident prone locations. Field inspections were made of thirty bridge sites randomly selected from this list, and the general nature of the alignment, grade, roadway widths, etc., were noted for each bridge and its approaches. A summary of the results of the field inspections is given in Table IV.

TABLE IV  
A SUMMARY OF FACTORS WHICH COULD CONTRIBUTE TO ACCIDENT FREQUENCY OR SEVERITY AT 30 PRIMARY AND ARTERIAL HIGHWAY SYSTEM BRIDGE SITES

Br. No.	Narrow Br. Roadway Width (< 28')	Appr. Roadway Curved	Bridge Curved	Entr. Int. or Intchg. adj. to Bridge	Pavement Transitions or Lane Reduction on Br. Appr.	Downhill Approach (d)	Uphill Appr. (d)	Low Vert. Cl.	Limited Horiz. or Vert. Sight Dist. on Appr.	No Appr. G.R.	Appr. not Anchored to Br. Rail	Slick Deck Surf.	Narrow R.R. Underpass	Other Misc. Factors (c)	WB WR Ratio of Br. to Appr. Roadway Width	Ave. Daily Trff. (1969)
1	X			X		X				X					0.68	9720
2	X	X	X	X		X				X	X				N.A.	9720
3	X									X					0.68	8470
4	X					X			X		X				1.00	3925
5	X					X				X	X				0.85	2310
6	X(a)		X			X	X			X					0.68	3950
7	X		X	X		X	X			X					0.68	11115
8	X					X				X	X				0.68	5240
9	X			X		X				X					0.64	3835
10	X			X	X	X				X			X		N.A.	4905
11	X					X			X	X	X				0.67	3835
12	X								X	X					0.68	2210
13	X			X						X					0.62	13825
14	X			X		X		X		X					0.60	3145
15	X					X		X		X					0.60	2495
16	X					X				X					0.60	465
17	X(e)			X		X				X				X	0.68	4585
18	X					X			X	X					0.74	1220
19	X			X		X			X	X					0.68	4180
20	X			X		X				X	X				N.A.	3270
21				X			X			X	X				N.A.	2890
22			X		X	X	X			X	X				N.A.	14120
23		X	X			X	X			X	X				N.A.	
24	X					X	X			X					0.68	34370
25	X		X	X		X	X			X			X		0.68	22500
26		X	X		X	X	X			X	X	X			N.A.	25220
27			X	X			X			X					N.A.	27155
28		X	X	X			X		X	X					N.A.	26335
29	X					X		X		X			X		N.A.	5220
30	X					X				X			X		N.A.	7085
TOT.	21	20(b)	8	13	4	22	9	3	9	18	12	1	2	4		

(a) Bridge subsequently widened from 23' roadway to 40' roadway.

(b) For at least one direction of approach, 17 of these 20 sites have approach roadway curvature to the left and 9 have curvature to the right.

(c) Includes unusual factors such as an at grade railroad crossing adjacent to the bridge, short irregular dip in approach grade, etc.

(d) Where no designation is given in either category, the grade is relatively slight and difficult to ascertain by visual inspection.

(e) Bridge subsequently replaced with a box culvert.

N.A. Not applicable due to pavement transitions, interchange ramps, or other variable conditions on the bridge or bridge approach.

## Geometrics

The four most prevalent geometric factors found at the locations were: (1) Downhill approach conditions, (2) narrow bridge roadway widths, (3) curved approach roadway, and (4) entrances or intersections adjacent to the bridge. The order of the dominating factors is much the same as that summarized from the state police questionnaire replies — with the exception of downhill approach conditions. Since most bridges cross streams in relatively low lying areas, downhill approach conditions might be expected to be a predominant feature of most locations. Only four (13%) of the sites were generally uphill in both directions of approach whereas seventeen (57%) were generally downhill in both directions of approach. Fifteen (68%) of the structures with downhill approaches had approach roadway curvature and (70%) of those with approach roadway curvature had narrow bridge roadway widths. All three of these factors were present at 50% of the sites with downhill approaches. Due to the combined nature of these factors it cannot be concluded that downhill approach would actually be the single most prevalent contributing factor. Considering the fact that snow and ice conditions existed during 21% of the accidents studied (Table V), however, it is probable that downhill gradients are often a contributing factor from this standpoint in addition to affecting vehicle speeds. Considered as an individual element, Kihlberg and Tharp<sup>(13)</sup> found gradients to be less significant than the presence of factors such as curvature and intersections. Thus, the high occurrence of combined geometrical factors at the sites surveyed in this study appears to be significant since the likelihood of a bridge site having combined geometrical factors decreases with increased numbers of factors involved. Similarly, only a small percentage of all the arterial and primary bridges have intersections or pavement transitions immediately adjacent to the structure. Yet, intersections (or entrances) and pavement transitions were located at, respectively, 43% and 13% of the sites recorded in Table IV.

TABLE V

PRIMARY AND ARTERIAL BRIDGE ACCIDENTS WHERE  
SNOW AND ICE WERE PRESENT (1966)

Surface Conditions	Number of Accidents	Total Accidents Studied
Ice Present	76	
Snow Present	39	
TOTALS	115	554



Findings similar to those discussed above have been reported by Kihlberg and Tharp<sup>(13)</sup> who found that the presence of structures, curvature, gradients, and intersections generally have an increasing effect on accident rates. More significantly they found that combinations of any of these elements generated higher accident rates than the presence of individual elements. In addition, the presence of curvature and structures tended to have an increasing effect on single vehicle accident rates.

Referring again to Table IV, 85% of the 20 sites having approach roadway curvature were left curved alignment whereas only 45% were curved to the right. Brown and Foster<sup>(16)</sup> in a study of bridge accidents in New Zealand found that the right curved approach alignment contributed to three times more accidents at the left hand approach and bridge endpost. Since New Zealanders drive on the left hand side of the road, the analogous situation in the U. S. would be the left curved approach condition. Thus, the present study result is consistent with that of the New Zealand study.

Bridges with narrow roadway widths -- particularly those with widths equal to or less than the approach pavements -- have been shown by others<sup>(14, 15)</sup> to be locations of high accident rates. Brown and Foster<sup>(16)</sup> found that 70% of the accidents occurred where the ratio of the bridge roadway width,  $W_B$ , to approach roadway width,  $W_R$ , (including the shoulder width) was  $\leq 0.79$ . A similar ratio could be determined on 19 of the sites surveyed in this study. Seventeen, or 90%, of these had  $W_B/W_R$  ratios less than 0.79. Sixteen, or 84%, had ratios less than 0.69. It is apparent that many older bridges constitute a potential hazard due to narrow roadway widths.

Another geometric feature included in Table IV concerns limited sight distance on approaches, which is usually related to outdated alignments and gradients. Low vertical clearance was also found on several of the older through truss type bridges, and is also a problem on some railroad underpasses.

#### Bridge Approach Guardrail

Sixty percent of the sites included in Table IV had no approach guardrail at all, and at all the remaining sites the guardrails were not anchored or bolted to the ends of the bridge railing (or abutments). In the former case, the ends of the bridge railings can be struck head on, and in the latter case any lateral displacement of the approach guardrail could also allow a vehicle to impact with the ends of the bridge railing. Olson, et al,<sup>(17)</sup> report, for example, that more than 50% of the 1966-67 fatal accidents involving bridge railing systems in California occurred at the ends of the bridge railings. Bridge ends not protected by an approach guardrail accounted for 34% of the fatalities whereas 18% resulted from collisions with end posts where the existing approach guardrail did not provide structural continuity with the bridge railing. Four of the five states surveyed by Olson reported that the highest percentage of fatalities in collisions with bridge railing

systems occurred at the ends of the bridge railings. Seventy percent of the fatal accidents occurred against the bridge endposts in the study conducted by Brown and Foster. (16)

Considering the effects of other factors from Table IV, 16 of the 18 bridges with no approach guardrail have narrow roadway widths and 11 of the 18 have approach curvature. Even where geometric type contributing factors are at a minimum, severe collisions with the ends of bridge railings sometimes occur. Figure 2, for example, shows a primary highway system bridge with a relatively flat grade, straight alignment, and few geometric complications. At approximately 0.68, however, the  $W_B/W_R$  ratio is low and the ends of the rigid concrete rails are not protected by approach guardrail. Figure 3 shows the results of a head on collision with the right hand end post of the same structure. Details of the accident, which occurred late at night, are lacking since the only occupant was killed. Approach guardrail may not have prevented injury in this particular case, but it may have prevented a fatality. It is apparent that the severity of collisions with bridge endposts could be reduced at many locations in Virginia by the installation of guardrail systems — particularly those that will provide structural continuity between the approach and bridge railings. Exposed ends of railroad abutment wingwalls at highway underpasses present a similar type problem at structures typical of numbers 29 and 30, Table IV.

#### Case Studies

Discussion of some case study examples can serve three purposes: (1) To indicate the general types of accidents that occur at some typical accident prone bridge sites, (2) to explore possible safety improvements at some of these locations, and (3) to illustrate how on the site field inspections supplemented by accident report information can sometimes reveal roadway factors which could contribute to accidents.

The first case study bridge has had a history of accidents — one fatal — and was recently involved in a sequence of collisions. When a narrow roadway width bridge is located within a passing opportunity section of a two lane highway such as that shown in Figure 4, collisions involving the bridge railings appear to occur more frequently than when this situation does not exist. This 22 ft. long, 23 ft. clear roadway bridge was involved in a passing type accident in August 1969 when a westbound vehicle met an eastbound vehicle passing another eastbound vehicle. The westbound vehicle went into a skid to avoid the eastbound vehicles, crossed to the opposite side of the road, knocked out the east end of the bridge railing (Figure 5), and went over the edge of the structure. The railing was rebuilt but in March 1970 an eastbound vehicle, forced over by a passing vehicle, knocked out the west end of the same railing (Figure 6). Subsequently, the rail was rebuilt, but in May 1970 an eastbound tractor-trailer, after being forced off the edge of the approach roadway, struck the same rail knocking it out entirely (Figure 7).



Figure 2. View of bridge #3 in Table IV showing excellent alignment and sight distance characteristics but the restricted roadway width and exposed ends of the rigid concrete railing constitute a potential hazard.

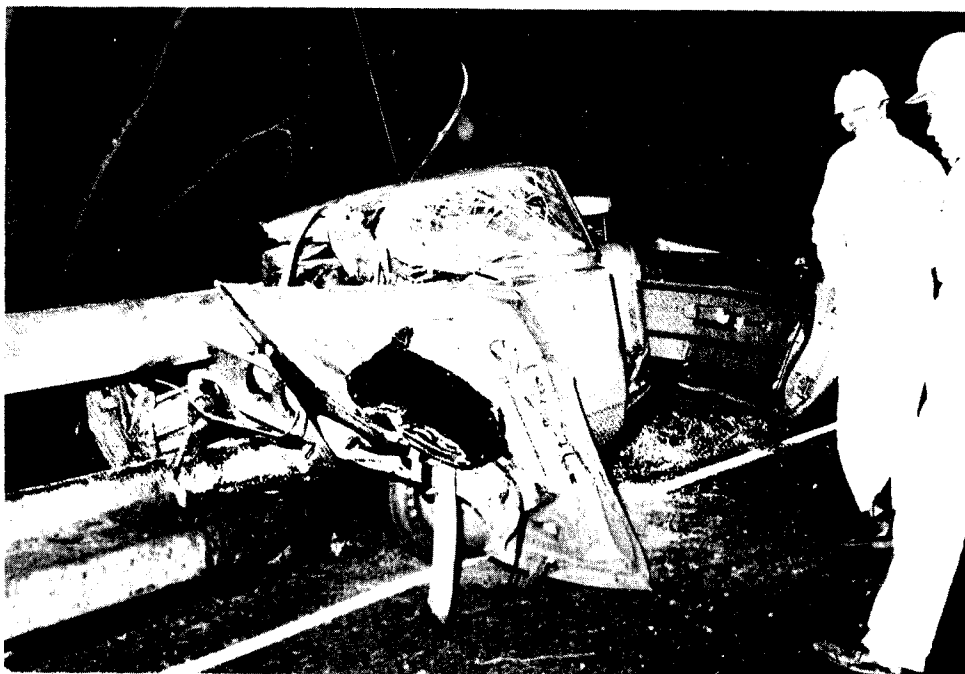


Figure 3. The results of a head-on collision with the right hand end post of the bridge shown in Figure 2.



Figure 4. A narrow roadway with bridge located within a passing opportunity section of a two lane highway. An intersection is located to the right adjacent to the structures. (Bridge #1 of Table IV.)

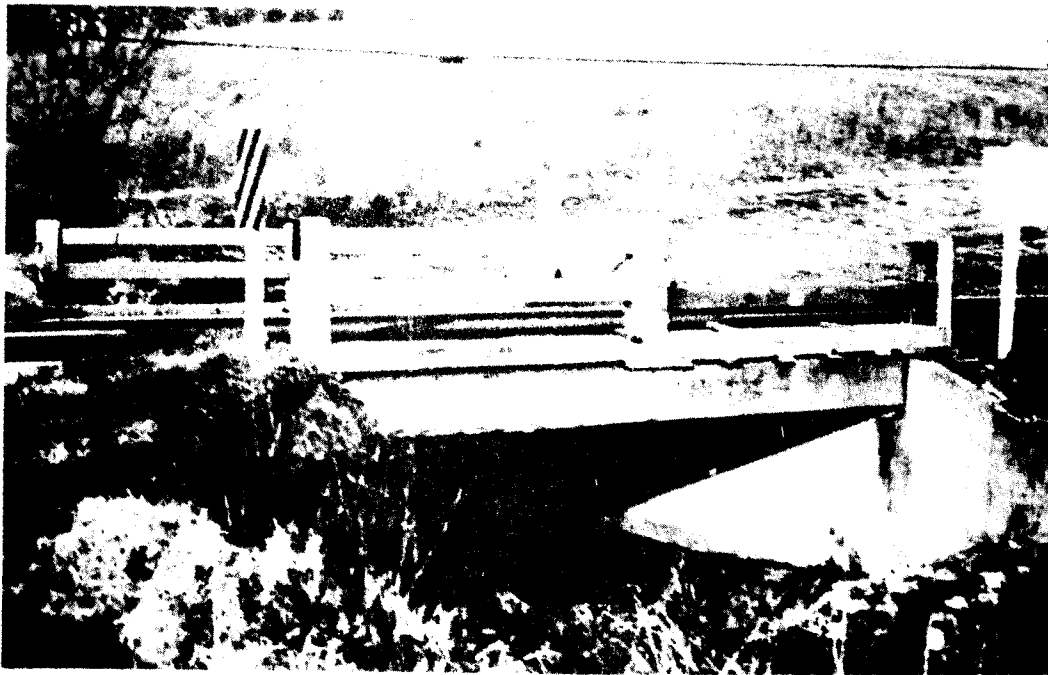


Figure 5. Close-up view of the bridge in Figure 4 showing temporary wooden rail which has been used to replace the knocked out east end of the concrete rail. (Date of accident — August 1969.)

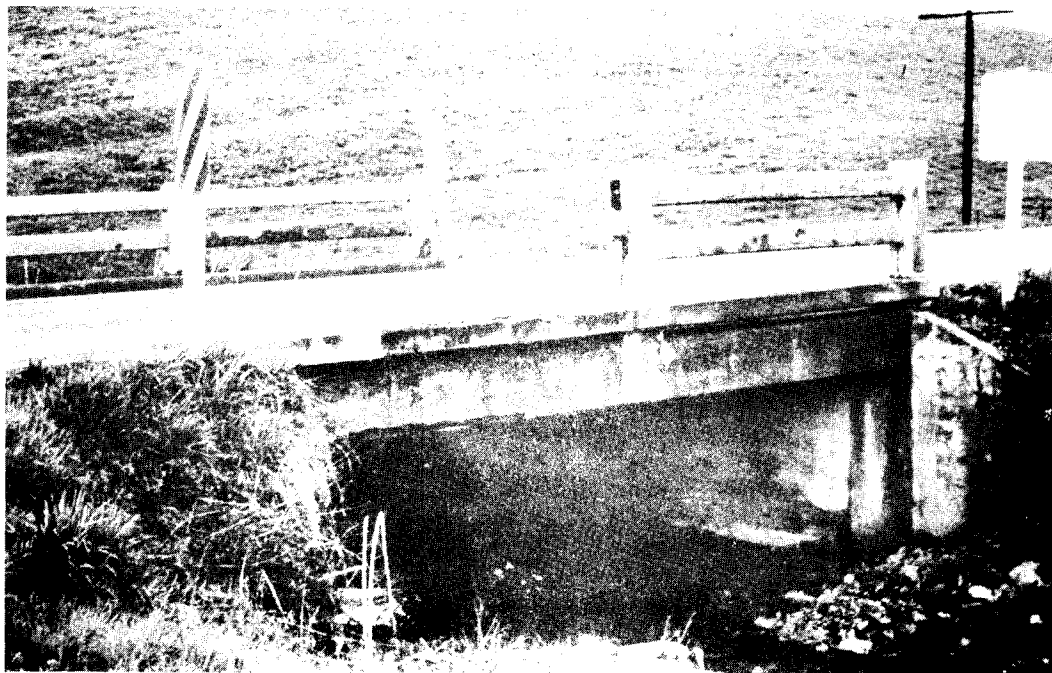


Figure 6. The same structure as shown in Figures 4 and 5. The east end of the concrete rail has been replaced and the west end subsequently knocked out. (Date of accident — March 1970.)



Figure 7. The same structure as shown in Figures 4, 5, and 6. Subsequent to March 1970 the concrete rail was rebuilt but later knocked out entirely and a temporary wooden rail again installed. (Date of accident — May 1970.)

The rail was again rebuilt and in November 1970 the east end of the railing on the opposite side of the road was knocked out (Figure 8) by an out of control eastbound vehicle. The last two accidents were single vehicle property damage types and no reports were filed. (Details of the two accidents were obtained from a resident living adjacent to the bridge site.) In each of the two accidents, the steep slope off the edge of the main roadway pavement to the adjacent intersection may have been a contributing factor (See Figure 4). The truck driver, for example, was unable to get the rear wheels of his trailer back onto the pavement to avoid hitting the bridge railing. Still another vehicle lost control by running off the pavement in the same area. Note also that the pavement edge striping is discontinued across the intersection. Under certain circumstances this could be a contributing factor and is discussed further in a later case study.

It is difficult to determine the total economic losses from the series of accidents described since property damages are only estimated by the reporter, some damages are not reported at all, and medical expenses are unknown. A reasonable estimate of the property damages, which occurred during a 15-month period, can be made as follows:

Personal property damages on two reported accidents	\$3,000
Personal property damages on two unreported accidents	1,000
Four repairs of handrail at average cost of \$432* each	<u>1,728</u>
Total	\$5,728

If medical costs, lost wages, etc., were included in the above estimate, the total economic losses would have been higher.

The second case study bridge #6 (of Table IV) was very similar to bridge #1. It too was located on a two lane highway in a passing opportunity area and had a narrow width roadway. According to the state police questionnaire replies several accidents and one fatality have resulted from collisions at the site in recent years. This 32 ft. long structure, however, was recently widened by state forces from a 23 ft. to a 40 ft. roadway width at a cost of \$17,000\*\*. Figure 9 shows a view of the widened structure.

---

\*Average cost figure supplied by R. G. Warner, Resident Engineer, Virginia Department of Highways.

\*\*The cost figure for this improvement was provided by Mr. L. L. Misenheimer, Staunton District Bridge Engineer, Virginia Department of Highways.



Figure 8. The same structure as shown in Figures 4 through 7. Here the south rail has been rebuilt; the east end of the north rail knocked out. (Date of accident — November 1970.)

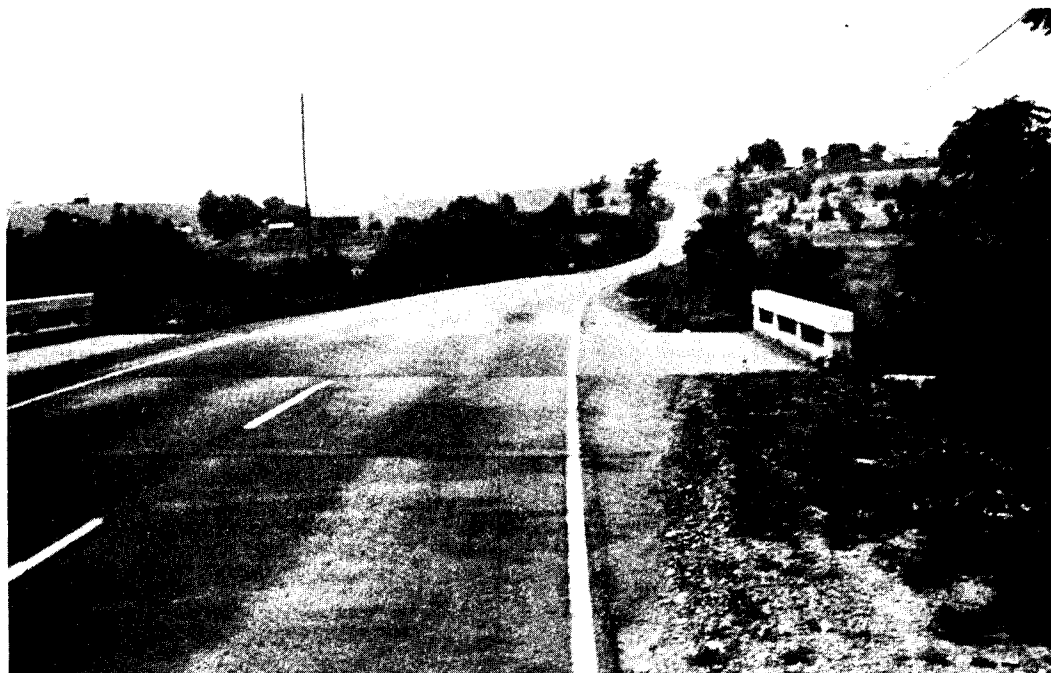


Figure 9. A 32 ft. span, 40 ft. roadway bridge which was widened from a 23 ft. roadway. As a secondary measure, an approach guardrail anchored to the bridge rail would further enhance this safety improvement.

Curves which can be used to forecast accident reductions and fatality-injury and property damage reductions through the widening of bridges have been developed by Jorgensen and Associates<sup>(18)</sup> and are shown in Figures 10 and 11. By extrapolating the curve  $D = 0$  of Figure 10, it can be estimated that an average reduction in accidents of approximately 95% can be expected from the 17 ft. widening of bridge #6. A similar reduction in property damages and injuries could be expected by extrapolation of the curves given in Figure 11. Benefit and cost estimates can be calculated for the widening improvement by using the methodology presented in reference 18. Thus, for an annual cost of \$985 the widening of bridge #6 will yield estimated average annual benefits of \$11,350 for a benefit to cost ratio of 11.5. (See Appendix B for calculations.) Since the two structures are quite similar, bridge #1 could be widened for approximately the same cost as bridge #6. The annual cost of such an improvement would be less than one fifth the \$5,728 property damages estimated for the recent series of accidents.

Installation of guardrail in lieu of widening at either of the two bridges would not reduce the number of accidents. As a result, maintenance costs for repairs would likely remain high if such an alternative were selected. Again, using the forecasts and methodology from reference 18, it can be estimated that the average annual benefits to be derived from a guardrail installation would be \$2,520 while the annual cost would be \$433 -- yielding a benefit to cost ratio of 5.8. Thus, widening in each of these two cases would be the better alternative.

It should be emphasized that the benefits to be derived from guardrail installations at bridges are due solely to a reduction in accident severity. Therefore, the benefits derived from the widening of short span bridges typical of those discussed above should not be confused with the need to reduce the severity of collisions with structures typical of the one shown earlier in Figure 2. In the latter type situations many older bridges which constitute potential fixed object hazards should be upgraded to comply as nearly as possible with the bridge rail service requirements developed by Olson, et al. <sup>(17)</sup> Three of the ten requirements (Appendix C) that are particularly germane to the deficiencies found on many existing bridge rail systems are:

- (1) A bridge rail system must laterally restrain a selected vehicle.
- (2) A bridge rail system must remain intact following a collision.
- (3) A bridge rail system must have a compatible approach rail or other device to prevent collisions with the end of the bridge rail.



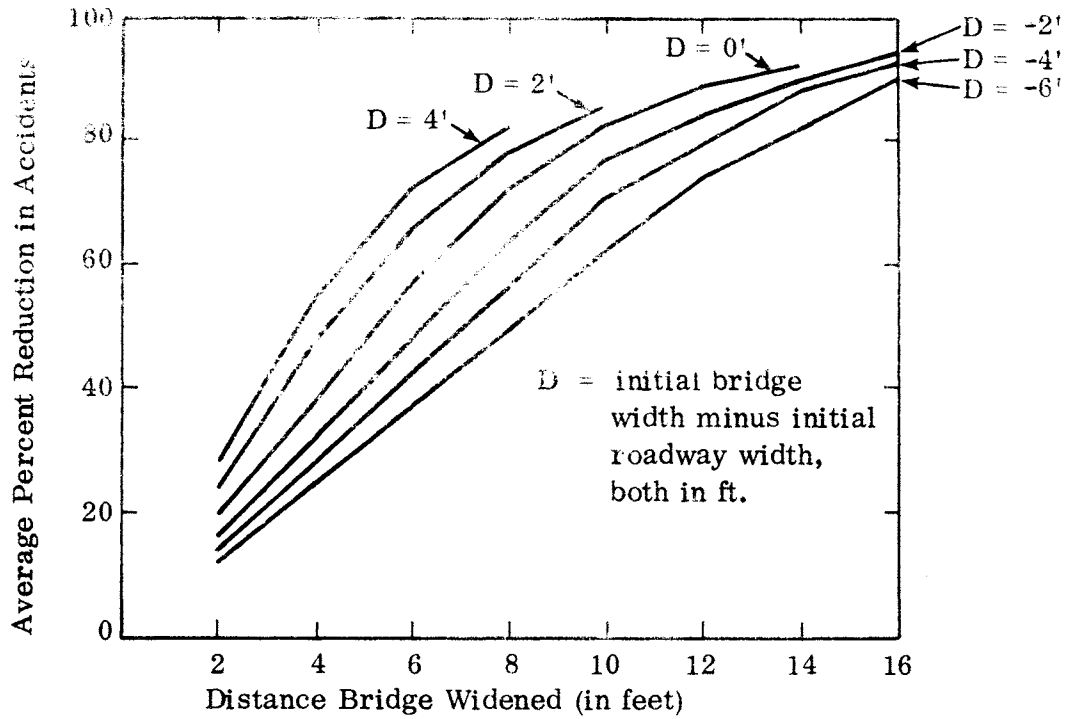


Figure 10. Forecast chart of accident reduction through widening bridges. (From Reference 18.)

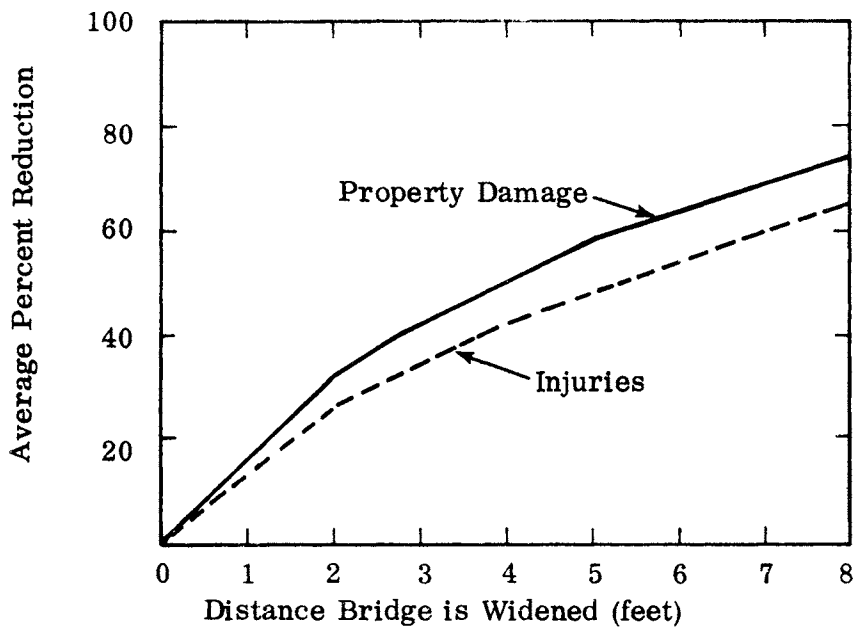


Figure 11. Forecast of fatality-injury and property damage reduction through widening bridges. (From Reference 18.)

Progress toward meeting these three requirements has been made at several locations. In Figure 12, for example, structural continuity between the approach rail and bridge rail has been obtained by a closer spacing of the approach rail posts adjacent to the bridge rail and by continuing the guardrail across the length of the bridge. In addition, the ability of the rail system to laterally restrain a vehicle and to remain intact after a collision is enhanced by anchoring the continuous guardrail to the bridge rail. Similar rail systems have been advocated by Tutt and Nixon<sup>(19)</sup> and the results of the present study suggest that a progressive program is needed to extend these type treatments to include as many bridges on the primary and arterial system as would be practical.

Slowing, stopping, or turning traffic at intersections, business entrances, etc., increase accident potential. When bridges happen to be located adjacent to points of high accident potential their potential for involvement also appears to be increased; thus, to some extent creating a situation of double jeopardy. A typical example is given in Figure 13, which shows a narrow roadway width bridge located adjacent to an intersection where traffic slows or stops for left turns. Collisions with the right-hand bridge rail have resulted from situations where one vehicle maneuvers to avoid collision with other vehicles making turning or lane change maneuvers. A business entrance adjacent to the right approach to the bridge probably adds to the traffic conflicts at this particular location. Widening of the short span bridge would probably be the best alternative for removing this particular fixed object hazard.

In the next case study seven fatalities have resulted from single vehicle collisions with the right endpost of the bridge rail. In two separate collisions within a period of several weeks six fatalities resulted from the first, and one from the last. Both accidents occurred at night and visibility was poor due to fog or rainy conditions. In these two accidents and another in the 1966-67 period driver fatigue could have been a factor. Approaching the bridge (Figure 14) there is a transition from two to four lanes occurring simultaneously with a curve to the left. The approach pavement edge marking is discontinued on the right at an adjacent intersection, and there is no centerline lane marking in the pavement transition area. Considering these factors and the environmental and visibility conditions existing at the time of the accidents it is possible that each driver mistook the intersection to the right for the main roadway. Accordingly, they could have been misled to the extent that their recovery course headed into the bridge endpost. Alternately, if the pavement edge marking was being used as a guide, one would be headed on a course beginning from the point where the pavement edge marking is discontinued and directed toward the bridge endpost -- while the road actually curves leftward. Thus, under the circumstances, the pavement transition, the curve to the left, the intersection to the right, and the discontinuation of the pavement edge marking could all have been contributing factors in these accidents.

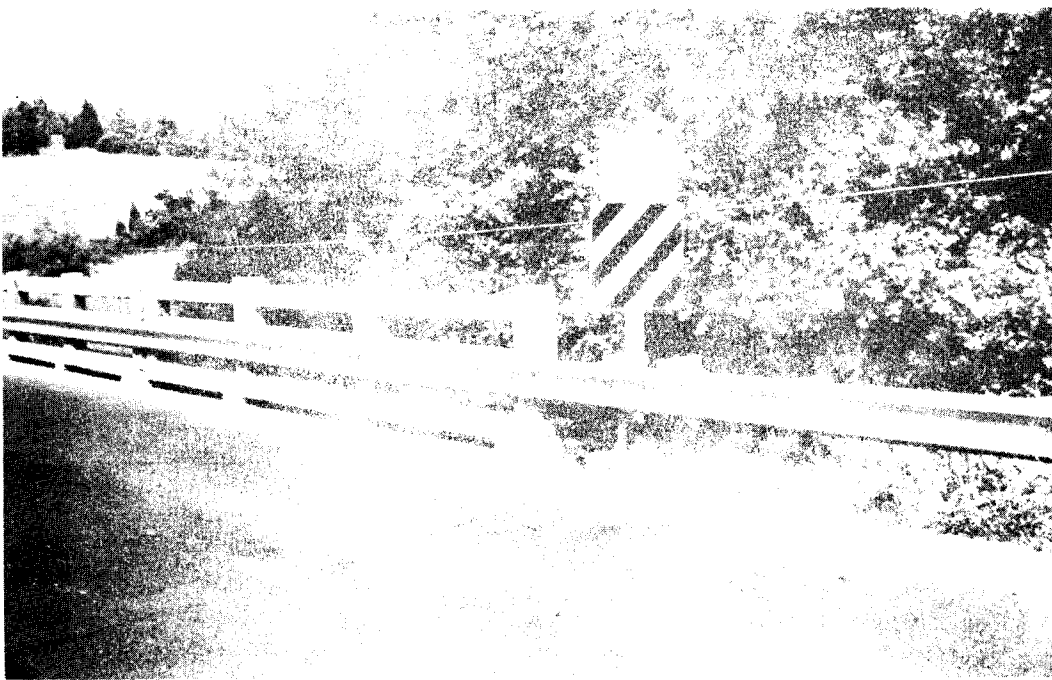


Figure 12. Approach guardrail continued across a bridge in front of the bridge railing.



Figure 13. A narrow roadway width bridge located adjacent to an intersection (center) and business entrance (right foreground). A temporary wooden rail replaces the knocked out concrete rail on the right side of the bridge. (Bridge #24, Table IV.)

The results from this study as illustrated by the last two examples, suggest that intersections should be located as far away from bridge sites as possible in design. Where intersections are located adjacent to structures the main roadway pavement edge marking should be continued across the intersection. When advantage can be taken of main roadway gradients, intersections should be located to give maximum sight advantage over the bridge railings.

Each approach to the bridge in the next example (Figure 15) has a transition from four lanes to two lanes. It might be expected that transitions of this type would tend to have an effect similar to that of widening the roadway but not the bridge. This practice, as prior studies<sup>(15,18,20)</sup> have shown, results in increased accident rates. Many of the accidents at the structure in question have been related to passing maneuvers on the bridge or its approaches. In a recent accident of this type a truck went through the steel railing (Figure 16) and off the bridge -- killing the driver. Although the bridge is now marked as a no passing zone, it appears that the four lane highway on each side of the bridge creates a psychological "freedom to pass" attitude that prevails on the two lane bridge as well. The rail penetration incident might also suggest that reinforced concrete parapet walls should always be used on the larger, higher, major structures such as this one.

Each of the last two examples demonstrates the general finding that pavement transitions on bridge approaches should be avoided. When transitions are necessary, however, they should be completed well in advance of the structure to allow drivers maximum opportunity to adjust to the change prior to entering the bridge. Forbes<sup>(21)</sup> reports that driver tasks, depending upon the degree of complexity, can require up to 3 or more seconds. Allowing for lower illumination and other conditions which reduce visibility this response time might be more than doubled. If additional adjustment time were allowed, 10 to 12 seconds might be a reasonable time estimate; and at normal speed limits a minimum distance of 1000 to 1200 ft. between the bridge and the completion of a lane transition should be allowed.

Inspection of the scene of an accident can sometimes reveal contributing roadway factors that are more related to maintenance or construction than to design and obsolescence. An example of such a case is shown in Figure 17 where several skidding type accidents had occurred on the bridge deck during wet surface conditions. Significant portions of the deck had been repaired with an epoxy surfacing material which had not been treated with a deslicking grit (sand) during the initial application. McKeel<sup>(22)</sup> has found that epoxy overlays lose their skid resistance rather rapidly as the initial grit application is lost due to wear. An epoxy surface with no initial deslicking treatment could thus be expected to polish rapidly under traffic wear and become very slick.



Figure 14. A bridge located at the end of a pavement transition section. Two fatal accidents have occurred in collisions with the right-hand endpost. (Bridge #10, Table IV.)



Figure 15. A transition from four lanes to two lanes on the approach to a major bridge crossing. (Bridge #22, Table IV.)

1682

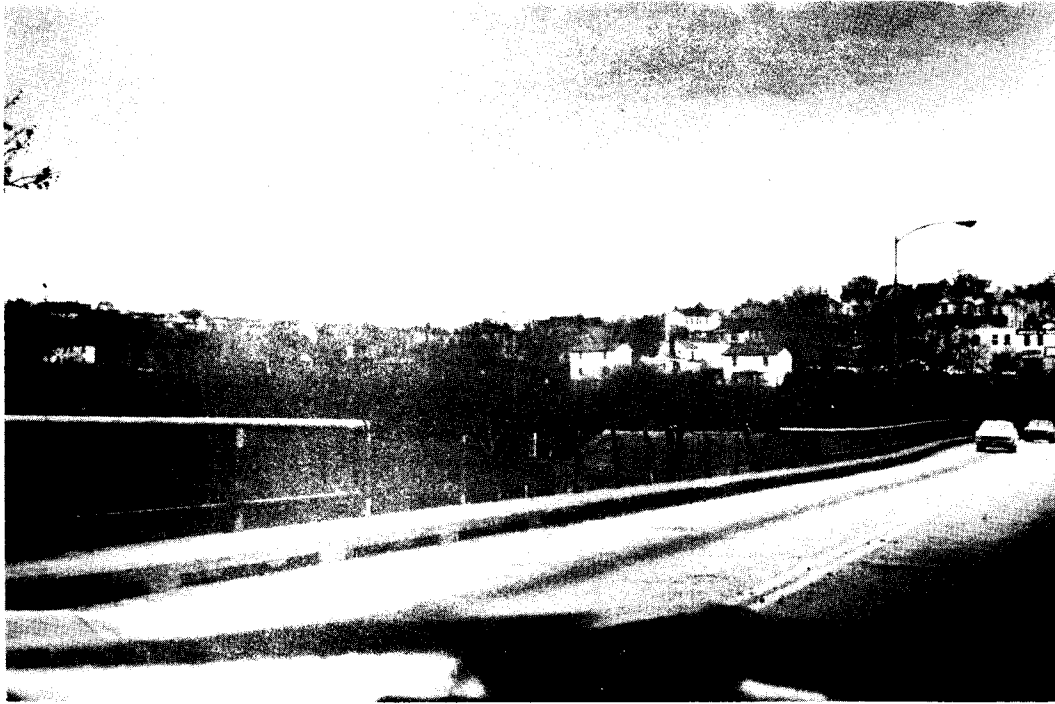


Figure 16. Penetration of the steel railing of bridge #22 resulting from a truck collision.

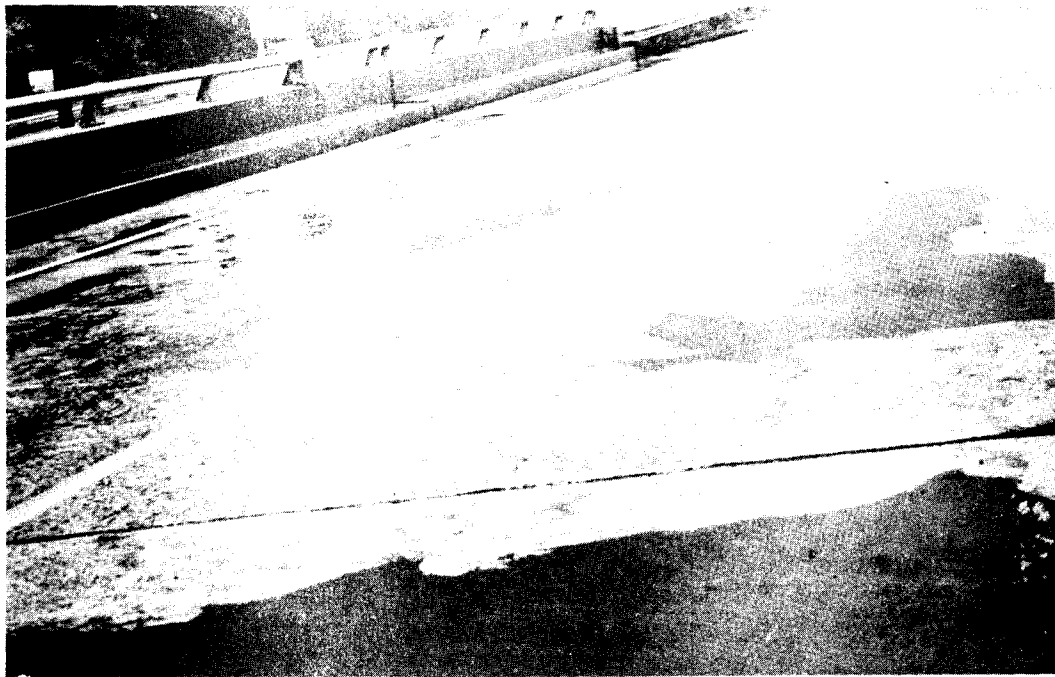


Figure 17. An epoxy surface treatment with no initial deslicking sand application probably contributed to several skidding accidents on this downhill and superelevated bridge deck. (Bridge #26, Table IV.)

## Interstate Bridges

A total of 201 accidents at interstate bridges were reviewed. For the bridges having two or more accidents during 1966, the roadway geometrics were obtained from the roadway plans for comparison with the accident data.

### Geometrics and Accident Data

For 27 bridge sites\* a summary of certain approach roadway geometrics and accident data was tabulated. The approach geometrics were broken down into three ranges of curvature, two ranges of grade, and combined curvature with downhill grade and tangent with downhill grade. The accidents were divided into five general categories as determined from the description given on the reports. Other general accident data such as surface conditions, vehicle speed, driver defects, and vehicle defects were included in the summary which is given in Table VI. These data show little that would not be expected. The majority of the accidents are single vehicle types followed by accidents associated with passing maneuvers and slowing, stopping or stalled vehicles. Roughly two-thirds to three-quarters of all the accidents involved a collision with the bridges.

Sixteen of the sites have curved approaches, with 13 of these being 1° or less. Twenty-three of the sites have downhill approach conditions and generally the higher the percent of grade and the higher the degree of curvature, the greater the relative percentage of accidents during wet surface conditions. There was no definite trend in this regard for snow and ice conditions, but one-quarter to one-third of the accidents occurred when these type conditions prevailed. Approximately 50% of the accidents occurred when the bridge deck surface conditions were either wet, snowy or icy whereas, for comparison, these conditions existed in 31% of all accidents on the total interstate system during 1966. (1) Of 42 individual bridges involved in two or more 1966 accidents, 62% are approached by a downhill grade of 1,000 feet or more in length. An additional 24% have downhill approach lengths of greater than 500 ft. Thus, the most dominant factor in the bridge accidents appears to be adverse surface conditions — particularly when longer and steeper approach grades are present.

At one bridgesite (Rte. 95 over the Meherrin River) 6 of 17 accidents reviewed for the period 1963-1967 involved icy conditions on the bridge deck. These two structures are approached on the north bound lane by a 1.4% downhill grade of approximately 1600 ft. in length and in the south bound lane by a 3.5% downhill grade of approximately

---

\*In most cases there are two separate bridges for each site.

TABLE VI  
ROADWAY APPROACH GEOMETRICS AND 1966 ACCIDENT DATA FOR 27 INTERSTATE BRIDGE SITES (a)

Bridge Approach Condition	Br. Sites		Acci. No.	Vehicle Struck Bridge %	Accident Type				Surf. Condition			Vehicle Speed MPH			Driver Defects Invol. %	Vehicle Defects Invol. %	
	No.	%			Pass. %	Slow Stop %	Sing. Veh. %	Multi-Veh. (b) %	Misc. %	Dry %	Wet %	Snow or Ice %	50 %	50-60 %			60 %
Curved $\leq 10^\circ$	13		68	66	19	24	37	10	8	50	28	22	37	25	38	15	21
Curved $> 10^\circ \leq 30^\circ$	1		1	100	0	0	100	0	0	100	0	0	0	100	0	--	--
Curved $\geq 30^\circ - 50^\circ$	2		14	100	14	7	50	21	7	14	57	28	43	36	21	7	21
Grade $\leq 2\%$	15		69	64	20	25	43	7	4	51	19	30	43	20	36	16	17
Grade $> 2\% \leq 4\%$	12		59	76	17	15	51	6	7	41	34	23	36	25	39	12	17
Curve and Downhill Grade	10		43	67	19	26	37	16	2	53	21	26	30	49	21	7	19
Tangent and down-hill grade	13		34	74	24	3	59	12	3	59	9	32	41	41	18	24	21

(a) An Interstate bridge site in most cases includes two separate bridges.  
 (b) This category includes the "chain reaction" type of accident.



600 ft. in length. Superposition of icy deck conditions on the long and relatively steep downhill approaches would explain some of the high accident frequency at this location. An ice warning device (such as that mentioned earlier) at this and similar locations might prove beneficial.

Considering all the 1966 bridge site accidents that were reviewed, 33% had icy or snowy (excluding wet) surface conditions. The comparable figure on the primary and arterial system bridges was 21% (see Table V). The higher percentage on the interstate bridges suggests that freer traffic flow and higher speeds on these type highways contribute to higher accident rates during icy and snowy conditions. Many drivers apparently are either not aware of the fact that when moisture is present during freezing temperatures ice will form on bridge decks before on the roadway, or they are not making adequate speed adjustments for poor surface conditions.

It is difficult to evaluate the bridge roadway-approach roadway relationships on all of the bridge sites investigated due to variations in ramp intersections at interchanges, etc. At 19 of the sites, however, it was found, as shown in Table VII, that 63% of the most accident prone interstate bridges had clear roadway widths in the 28-30 ft. range whereas the remaining 37% were in the 40-42 ft. range. Seventy-four percent of the sites had a bridge to approach roadway width ratio of less than 0.8. Though these data are limited, the results are in line with those on the primary and arterial system, i. e., bridges with  $W_B/W_R$  ratios less than 0.8 are generally more accident prone.

TABLE VII

BRIDGE AND APPROACH ROADWAY WIDTH RELATIONSHIPS  
AT 19 INTERSTATE BRIDGE SITES

Bridge Sites	Bridge Clear Roadway Width				Bridge Approach Roadway Width Ratio ( $W_B/W_R$ )			
	28' - 30'		40' - 42'		0.6 to 0.8		0.8 to 0.9	
	No. sites	%	No. sites	%	No. sites	%	No. sites	%
19	12	63	7	37	14	74	5	26

Draw and Swing Span Bridges

Factors contributing to accidents at four draw or swing span type bridges are summarized in Table VIII from comments made by state police officers. Inadequate warning to traffic approaching backed up, stopped or slowed vehicles was considered a major accident factor at three of the four bridges. Transitions from four lanes to two lanes on the bridge approach, stalled vehicles, and skidding on wet steel grated decks were next in order of the frequency mentioned.

TABLE VIII

FACTORS CONTRIBUTING TO ACCIDENTS AT DRAW AND SWING SPAN BRIDGES  
(State Police Comments)

Contributing Factor	Rte. 301 over Rappahannock River (Port Royal)	Rte. 17 over James River (Newport News)	Rte. 17 over York River (Yorktown)	Rte. 495 over Potomac River (Alexandria)
Inadequate warning to traffic approaching backed up, stopped or slowed vehicles	X	X		X
Transitions from 4 lanes to 2 lanes on bridge approach	X	X		
Low vertical clearance	X			
Stalled vehicles		X		X
Stopping for toll plaza		X		
Skidding on wet steel grated deck		X	X	

## Case Studies

Pavement transitions have been discussed earlier in the report and will not be covered further. The remaining factors listed above can be reviewed by case studies of accidents on the Rte. 17 bridge over the York River and the Rte. 17 bridge over the James River. These two case studies illustrate the major accident problems at the four sites and offer the added advantage of an evaluation of the effectiveness of steel studs (Figure 18) which were applied to the steel grated deck spans in late 1967 to reduce skidding accidents.

In 1966 there were 9 accidents reported on the Rte. 17 bridge over the York River. All occurred on the steel grating; seven during rainy weather and one during snowy conditions. In 1969, after the application of the steel studs, there were 3 accidents reported — all of which occurred during dry surface conditions and the steel deck was not considered to be a contributing factor. Neglecting a slight increase in traffic volume between 1966 and 1969, the 67% decrease in accidents indicates that the application of the studs has been very beneficial. Significant reductions in accidents have also been reported<sup>(23)</sup> in Pennsylvania where studs were applied to a number of steel deck bridges in 1967.

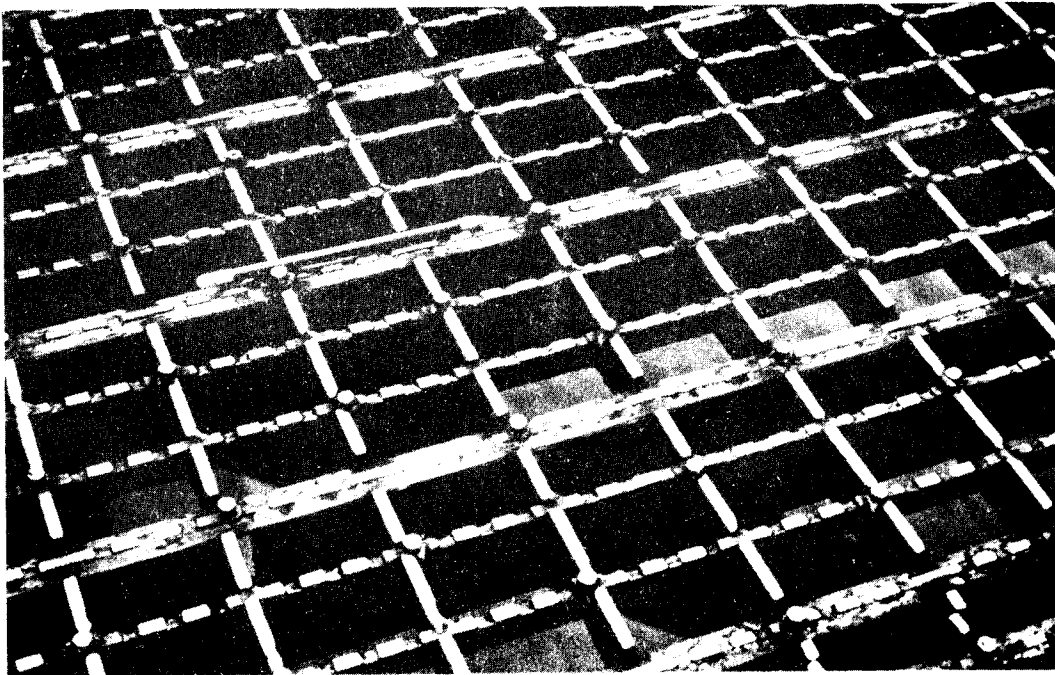


Figure 18. Steel grated deck with steel studs attached to improve skid resistance.

A comparison of the reported accidents on the 4.6 miles long James River bridge for 1966 and 1969 is presented in Table IX. The data indicate that slowing or backed up traffic rather than the slippery steel deck spans account for the large number of rear end collisions on this structure. The rear end accidents usually are related to traffic stoppage for the opened span, to slow moving vehicles, to stalled vehicles or to another accident. A common characteristic of the rear end collisions is a situation involving considerable traffic backup. This is in agreement with the comments of the state police who feel that approaching vehicles are not adequately warned of delayed traffic situations. In addition to the present warning system, they recommend installation of: (a) red flashing lights on the overhead truss structure for use during span openings, (b) amber lights spaced at 600 ft. intervals down the length of the bridge for use during stalled traffic situations and (c) flashing amber lights on the north and south sides of the toll plaza to warn approaching vehicles of slowing and stopping traffic. It is impossible to predict the effectiveness of the suggested installations, but due to the large number of accidents involved, these or similar warning installations should be given consideration at all three of the bridges where inadequate warning to approaching traffic (Table VIII) is considered a problem.

TABLE IX  
ACCIDENTS ON THE RTE. 17 BRIDGE OVER THE JAMES RIVER  
AT NEWPORT NEWS  
(1966 & 1969)

Year	Type of Accidents					Total No. of Accidents	Accident Rate*
	Rear End	Head- on	Passing	Single Vehicle	Miscellaneous		
1966	20	5	4	5	0	34	357
1969	18	4	10	7	10	49	357

\*Based on the number of accidents per 100 million vehicle miles traveled.

It is difficult in many cases to ascertain from the accident reports whether the steel grating on the Rte. 17 James River bridge actually contributed to certain accidents. In addition, since the accident rate for 1969 is the same as that for 1966, the effectiveness of the steel deck studs in reducing accidents cannot be determined. Considering that the steel decking represents only a very short distance of the total 4.6 mile length, however, the difficulty in using accident reports to evaluate the studding on this structure is to be expected.

## SUMMARY OF CONCLUSIONS

Evaluation of Accident Report Data for Use in Research

1. The current Virginia highway accident report is a good source of general information, but for roadway research purposes supplemental data from other sources are necessary for general evaluations of roadway factors. For specific evaluations of roadway and structural design features the information contained in the reports is usually inadequate.
2. The typical accident reports' usefulness to research is limited primarily by the inadequacies of the "check list" type format, lack of detail, and incomplete reporting.
3. It would be impractical to complete all accident reports in such a manner as to maximize their value to research. Accordingly, specially design accident reports should be used for specific roadway research objectives and the geographic area of study limited to carefully selected regions. (Suggestions along these lines are given in Appendix A.)

Questionnaire Replies (State Police and Highway Engineers)

1. Probably because accident investigation is one of their regular duties, state police officers are more likely than most highway engineers to recognize the more subtle roadway factors which might contribute to accident frequency and/or severity at bridge sites.
2. Some of the replying engineers appeared more inclined than did the state police officers to accept driver errors as the basic cause of most accidents. There was good general agreement between the two groups, however, regarding the most common roadway factors which they felt contributed to accidents at bridge sites.
3. Periodic formal meetings of limited scope between highway design engineers and state police officers might serve to define some areas where new design criteria would be beneficial to highway safety.

Arterial and Primary System Bridges

1. The results of the field inspections conducted in this study and the summary of the state police questionnaire comments were in general agreement regarding the most common roadway geometrics at arterial and primary system bridge sites with past accident histories.

These factors can be listed as follows:

- (a) Narrow bridge roadway width -- Accident potential appears to be higher at bridge sites where the ratio of bridge roadway width to approach roadway width (including the approach shoulder) is less than 0.80.
  - (b) Approach roadway curvature -- Left curved approach alignment appears to be a dominant factor. Of 20 sites surveyed which had approach roadway curvature, 85% had left curved alignment on at least one approach direction whereas 45% were curved to the right.
  - (c) Pavement transitions on bridge approaches -- Transitions from four lanes to two lanes and vice versa on bridge approaches tend to place greater demand on the perceptual and decision making capabilities of drivers. Accordingly, the potential for accidents involving structural components of the bridge appears to be increased.
  - (d) Intersections adjacent to bridges.
  - (e) Downhill approach gradients.
  - (f) Bridge curvature.
  - (g) Combinations of any of the above factors.
- (2) A significant number of older bridges (60% of those surveyed) on arterial and primary system have exposed rail endposts which constitute a fixed object hazard.
  - (3) Where guardrail is installed on bridge approach shoulders seldom is it anchored to the bridge rail in such a manner as to provide for structural continuity between the approach rail and bridge rail.
  - (4) The severity of accidents at many arterial and primary bridges in Virginia could be reduced by installing approach guardrails which are either effectively anchored to the existing bridge rail or continue across the full length of the bridge by attachment to the front face of the existing bridge rail.
  - (5) An analysis of a narrow roadway width single span bridge which has been widened suggests that widening would yield favorable cost to benefit ratios for similar improvements to other narrow roadway width short length bridges which have accident histories.

- (6) On two lane highways, narrow roadway width bridges which are located within passing opportunity sections appear to have greater potential for being involved in accidents.
- (7) Many of the existing bridge railings on older bridges will not restrain a standard sized vehicle nor will they remain intact following a collision. A recent penetration of a steel handrail on the Rte. 29A bridge over the James River at Lynchburg, Virginia, suggests that parapet (barrier) wall designs should be used on all major structures in the future.
- (8) The discontinuation of main roadway pavement edge striping at intersections adjacent to bridges may be misleading or confusing to motorists approaching such situations under certain adverse environmental or physical conditions.
- (9) Intersections and entrances adjacent to bridge sites appear to increase the potential of collisions with the structures. Factors involved include obstruction of view due to the bridge railings, increased traffic conflicts at the fixed object location, and under certain conditions, intersections can be confusing to the approaching motorist (see item 8 above).

#### Interstate Bridges

- (1) The most dominant factor in the 1966 bridge accidents studied on the interstate system was adverse surface conditions (wet, snowy, icy, etc.) — particularly when longer and steeper approach grades are present.
- (2) A larger proportion of accidents (33% of the 1966 accidents studied) occur on interstate bridges when icy or snowy surface conditions exist than on primary system bridges (21% of the 1966 accidents studied). This fact suggests that many motorists are either unaware that ice will form on bridge decks before on the roadway, or they are not making adequate speed adjustments for poor surface conditions on high speed highways.
- (3) Similar to the results on the primary and arterial system, interstate bridge sites appear to be more accident prone where the ratio of bridge roadway width to approach roadway width (including the shoulders) is less than 0.80.

Draw and Swing Span Bridges

- (1) Rear end collisions resulting from vehicles approaching unexpected situations of stopped, slowed or stalled or backed up traffic has been a major accident factor at three of the four bridges reviewed (see Table VIII of the report).
- (2) Based on a comparison of 1966 and 1969 accident data, the installation of steel studs on the steel grated deck of the Rte. 17 bridge over the York River has significantly reduced skidding accidents.

## RECOMMENDATIONS

Based on the results of this study, the following recommendations appear to be justified.

Existing Bridges

- (1) That a program be initiated requiring the ultimate installation of approach guardrail on all existing primary and arterial system bridges which are not scheduled for early replacement, which presently have no approach guardrail at all, and which have ADT volumes of 1000 VPD or greater. Abutments and piers of overpass railroads or other roadways should be included in such a program. For those bridge sites falling in the above category early preference should be given to the bridges which
  - (a) have a ratio of clear roadway width to approach roadway width (including the shoulders) of less than 0.80,
  - (b) have approach roadway curvature — particularly curvature to the left,
  - (c) have approach pavement transitions or lane drops,
  - (d) have intersections or entrances adjacent to the structure, (in some instances of course, installation of guardrail at these locations will be hampered), or
  - (e) are located within a passing opportunity section of roadway.

The approach guardrail should be designed to either overlap and be anchored to the ends of the bridge railing or continue across the length of the bridge attached to the front face of the existing bridge railing. At



overpass structures the approach guardrail should overlap and be blocked outward from the face of abutments to allow for maximum possible energy absorption.

- (2) That for existing bridge sites having approach guardrails which are not overlapped and anchored to the bridge railing, a secondary program be initiated requiring upgrading of these systems to meet the standards suggested above. The conditions and priority guidelines outlined above are also recommended.
- (3) That for short span length narrow roadway width bridges (typical of those shown in Figures 5 and 9 of the report) with accident histories, it is recommended that widening these structures to equal the full approach roadway shoulder width be considered the best alternative in the program outlined in paragraphs 1 and 2.
- (4) That liberal use of reflectorized paints on bridge endposts and railings and the use of reflectors (delineators) on bridge approaches be continued.
- (5) That main roadway pavement edge striping be continued across intersections which are located adjacent to or on the approaches to bridges.
- (6) That a high priority be given to the design and construction of bridges and improvements at locations where temporary transitions from four to two lanes on bridge (or underpass) approaches exist. (A case in point is the Rte. 29A bridge over the James River at Lynchburg, Virginia.)
- (7) That consideration be given to the state police recommendations (outlined in the report) regarding the installation of additional warning lights for approaching traffic on the Rte. 17 bridge over the James River and other toll draw span facilities having a high incidence of rear end collisions.
- (8) That interstate bridges with long downhill approach gradients that have been the scene of frequent accidents (such as Rte. 95 over the Meherrin River) be considered as potential locations for ice warning devices.

### Design

As precautionary considerations during planning and design:

- (1) Temporary or permanent pavement transitions on bridge approaches should be avoided. Where transitions cannot be avoided, a minimum distance of 1,000 to 1,200 ft. between the bridge and the completion of the transition should be allowed.

- (2) The location of intersections or entrances immediately adjacent to bridges should be avoided wherever possible in design. Necessary intersections should be located as far from the structure as possible; and where advantage can be taken of main roadway gradients, intersections should be located to give maximum sight advantage over the bridge railings.
- (3) The penetration of several bridge railings observed during the study tends to substantiate the current design policy of using barrier wall designs for bridge railings. It is therefore recommended that this design policy be continued -- particularly for use on all major structures.

#### General

- (1) That periodic formal meetings between state police representatives and design engineers be held. Each meeting should be restricted to a discussion of a specific roadway feature such as guardrails, bridges, etc., and scheduled to allow adequate time for the state police divisions to select and prepare case studies that they feel will demonstrate problem areas.
- (2) That through communications issued by the Highway Safety Division or others the general public be warned of the potential dangers on bridge decks due to early icing during periods of freezing temperatures when moisture is present.
- (3) That for any future studies of accidents involving bridges, special accident forms be devised to supply the data outlined in Appendix A, and the study be limited to carefully selected geographic areas containing bridges of particular interest.

## ACKNOWLEDGEMENTS

The authors express their appreciation to W. B. Shelton, Associate Traffic Engineer, Traffic and Safety Division, for his cooperation in supplying the accident reports used in the study. The excellent participation of the Virginia State Police Divisions, the District Highway Engineers, and L. L. Misenheimer, District Bridge Engineer, Staunton District, is also greatly appreciated. The assistance and guidance of W. T. McKeel, Jr., Highway Research Engineer, who originally proposed the study, are gratefully acknowledged.

This project was conducted under the general direction of J. H. Dillard, State Highway Research Engineer.



## REFERENCES

1697

1. Summary of Accident Data, State Highway Systems, Virginia Department of Highways, Richmond, Virginia (1966).
2. Summary of Accident Data, State Highway Systems, Virginia Department of Highways, Richmond, Virginia (1967).
3. Summary of Accident Data, State Highway Systems, Virginia Department of Highways, Richmond, Virginia (1968).
4. Summary of Accident Data, State Highway Systems, Virginia Department of Highways, Richmond, Virginia (1969).
5. Baker, Stannard J. , "Single Vehicle Accidents on Route 66", Highway Research Record 188, HRB, Washington, D. C. , (1967).
6. Lundstrom, L. C. , et al, "A Bridge Parapet Designed for Safety", Highway Research Record No. 83, HRB, Washington, D. C. , (1965).
7. Operation of the Ice Condition Detection System, Holley Carburetor Company, Warren, Michigan, (1966).
8. "'Ice-tronics' for Winter Safety", Virginia Highway Bulletin, December 1969.
9. "Highway Safety Action Program — Engineering Section", A Report of the President's Committee for Traffic Safety; Washington, D. C. (1966).
10. "Highway Safety Action Program — Research Section", A Report of the President's Committee for Traffic Safety; Washington, D. C. , (1966).
11. Garrett, John W. and Kenneth J. Tharp, "Development of Improved Methods for Reduction of Traffic Accidents," NCHRP Report #79, Highway Research Board, (1969).
12. "Highway Safety Action Program — Traffic Accident Records Section", A Report of the President's Committee for Traffic Safety; Washington, D. C. , (1966).
13. Kihlberg, J. K. and K. J. Tharp, "Accident Rates as Related to Design Elements of Rural Highways", NCHRP Report #47, Highway Research Board (1968).
14. Traffic Control and Roadway Elements — Their Relationship to Highway Safety, Automotive Safety Foundation (1963).

15. Gunnerson, H. E. , Iowa Narrow Bridge Accident Study, Iowa State Highway Commission, Ames, Iowa, (1961).
16. Brown, J. V. , and J. Foster, "Bridge Accidents on Rural Highways in New Zealand: Analysis and Appraisal", Proceedings of the Third Conference of the Australian Road Research Board (1966), Vol. 3, Part I, pp. 638-646.
17. Olson, R. M. , E. R. Post, and W. F. McFarland, "Tentative Service Requirements for Bridge Rail Systems", NCHRP Report #86, Highway Research Board, (1970).
18. Jorgensen and Associates, and Westat Research Analysts, Inc. , "Evaluation of Criteria for Safety Improvements on the Highway," A Report to the Bureau of Public Roads (1966), pp. 49-50, 151-152, 194-200.
19. Tutt, P. R. , and J. F. Nixon, "Roadside Design Guidelines", Highway Research Board, Special Report 107, Washington, D. C. , (1970).
20. Williams, Sidney J. and Carl E. Fritts, "Let's Build Safety into Our Highways," Public Safety, May 1955, pp. 22-23.
21. Forbes, T. W. , "Some Factors Affecting Driver Efficiency at Night", HRB Bulletin 255, 1960, pp. 61-71.
22. McKeel, W. T. , "An Evaluation of Epoxy Compounds as a Material for Patching and Protecting Concrete", Virginia Highway Research Council, Charlottesville, Virginia, March 1971.
23. Correspondence from K. C. Larson, District Engineer, District 3-0, Pennsylvania Department of Highways (1968).
24. National Safety Council, Traffic Safety Memo No. 113, July 1969.

APPENDICES





## ADDITIONAL ACCIDENT INFORMATION NEEDED IN RESEARCH

It is suggested that for possible future studies of roadway structures, the following additional accident information be obtained whenever possible:

1. Diagrams of the accident which would include (a) the approximate distance from the structure where control of the vehicle was lost or where an initial collision or abnormal maneuver occurred, (b) the path and the distance the vehicle(s) traveled before and after collision with the structure, (c) the approximate angle of departure from the roadway and angle of collision with the structure, (d) the location and description of the part of the structure involved, and (e) the approximate speed at impact with the structure. A sample accident diagram form, which has been used in another study<sup>(11)</sup> and is shown in Figure A-1, might aid in collecting the type data suggested.
2. An additional standard diagram would be desirable for recording the approximate degree of damage to vehicles striking structural components. This information could aid in evaluating the effectiveness of structural designs such as the bridge rail-guardrail systems now in use.
3. An additional section for the investigating officer to describe specific roadway factors which he feels may have contributed to the cause or severity of the accident.
4. The clear width of the bridge and the approach roadway should be measured and recorded at the accident site when bridges are involved.
5. More specific information is needed on the roadway alignment and grade in the area where the accident occurs. This information could best be obtained by channelling the accident report through the district highway office concerned, and would necessitate that the exact location of the structure involved be more clearly identified than is presently the case in some instances.
6. Photographs should be taken at the scene of accidents to complement and aid in the interpretation of other data.

1702

ACCIDENT DATA COLLECTION STUDY: PATH OF VEHICLE

ACCIDENT NO. \_\_\_\_\_

OHIO STATE HIGHWAY PATROL

CORNELL AERONAUTICAL LABORATORY, INC.

DATE \_\_\_\_\_ OFFICER \_\_\_\_\_

TRANSPORTATION RESEARCH DEPARTMENT

VEHICLE DATA YEAR \_\_\_\_\_ MAKE \_\_\_\_\_ MODEL \_\_\_\_\_ BODY STYLE \_\_\_\_\_

ODOMETER READING       ESTIMATED SPEED PRIOR TO IMPACT \_\_\_\_\_ AT IMPACT \_\_\_\_\_

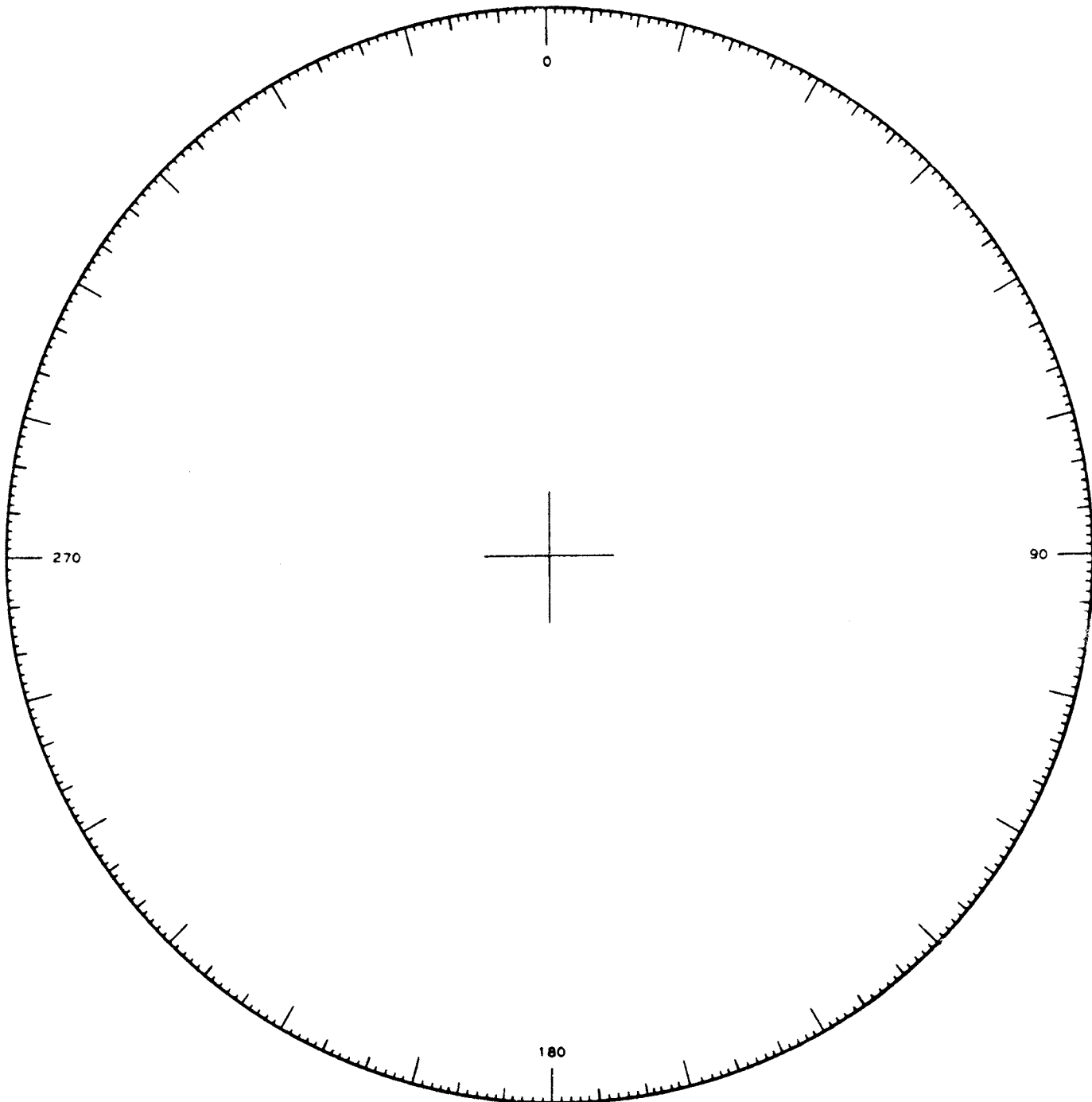


Figure A-1. (From Reference 11.) See instructions for use on next page.

SUPPLEMENTAL INSTRUCTIONS FOR COMPLETING  
PATH OF VEHICLE STUDY

DIAGRAM:

Single vehicle accidents:

1. Locate the point where the vehicle left the surfaced roadway. Place the clipboard parallel with the edge of the road at this point with the top of the clipboard pointing in the direction the vehicle was traveling. Leave in this position until all directions are marked.
2. Aim the pointer at the center of the vehicle. Mark this direction through the arrow on the pointer and label "V" for vehicle. Measure distance from point of departure to vehicle.
3. Aim pointer along path of vehicle departure if different than position at rest. Mark this direction and label "P".
4. Aim pointer at any object (tree, pole, etc.) struck by the vehicle, or any other item (ditch, embankment, etc.) that caused a change in path of vehicle. Measure distance from point of departure to object. Indicate road width. Clipboard may now be picked up.
5. Sketch the general arrangement of the roadway and the accident scene. Show any skid marks or traces of vehicle path as well as the orientation of the vehicle in its final resting place.

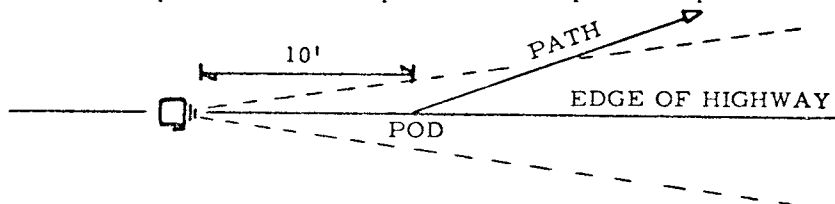
PHOTOGRAPHY:

Adequate photographic coverage is essential to this study.

What photographs are required?

Path of Vehicle.

1. From the clipboard at edge of highway take photograph of path of departure and vehicle in final resting position.
2. From a distance of 10 feet from the point of departure (see sketch) take a photograph centering the edge of the highway and point of departure in the view finder. To accentuate the path of departure in the processed photograph, place a yardstick or extended length of a tapemeasure on or parallel to the path of departure.



Highway and Berm. Again from position at clipboard photograph the edge of highway including berm in the direction from which vehicle was traveling.

Vehicle. Photos of the damaged vehicle are necessary. Close-up shots should be included.

Objects struck. Include photos of any or all objects struck by vehicle.

Full photographic coverage should consist of six to eight photos depending on circumstances.

Figure A-1 (continued)



## APPENDIX B

COST-BENEFIT CALCULATIONS FOR WIDENING BRIDGE #6 (TABLE IV),  
CASE STUDY #2. (USING PROCEDURES FROM REFERENCE 18, pp. 65-73.)

Costs: The net average annual cost of the widened bridge is calculated from:

$$\Delta H = C_1 K_1 + \Delta M \quad (1)$$

where,

$\Delta H$  = Net average annual cost of improvements

$C_1$  = Capital cost

$K_1$  = Capital recovery factor

$\Delta M$  = Change in annual maintenance and operation costs.

Assume:

30 year service life,

interest = 6%

Maintenance before improvement = \$300 per year

Maintenance after improvement = \$50 per year

Initial Cost of improvement = \$17,000

$$\Delta H = 17,000 (.07265) + (50 - 300)$$

$$\Delta H = \$985$$

Benefits: Annual benefits can be calculated from:

$$B = \$ (Q P_{FI} N_{FI} + 360 P_{AN} P_D) \frac{A_A}{A_B} (1 + F) \quad (2)$$

1706

where,

- B = Annual benefits, dollars
- $P_{FI}$  = Fractional reduction in fatalities-injuries
- $P_A$  = Fractional reduction in accidents
- Q = Average cost per fatality-injury = \$3,870 for rural highways in 1968. (see reference 18, pages 67-68, and reference 24 for Accident Cost data.)
- $N_{FI}$  = Annual number of combined fatalities and injuries prior to improvements.
- $N_{PD}$  = Annual number of property damage accidents.
- $A_A$  = Average daily traffic over the expected service life after improvements.
- $A_B$  = Average daily traffic for period immediately before improvements.
- F = Intangible benefits (suffering, grief, loss of life, etc.)

The following average annual accident record for the bridge site will be used in the calculations. Note that these figures are estimates which are believed to be reasonable based on the experience and information obtained from the study.

- 1.5 accidents
- 0.2 fatalities
- 1.0 injuries
- 1.5 property damage accidents

In addition the following facts and estimates will be used:

Approach pavement width:	23 ft.
Bridge width:	23 ft.
ADT (1969):	3,950 VPD
Estimated ADT next 20 years:	7,000 VPD
Bridge widened to:	40 ft.

The curves of Figures 10 and 11 can be extrapolated to obtain estimated values for  $P_{FI} = 0.95$  and  $P_A = 0.95$ . The value of  $F$  will be estimated at 0.3. Using all the information given above in equation (2):

$$B = \$11,350$$

Net Safety Benefit: The net safety benefit is equal to the annual dollar benefits,  $B$ , less the annual costs,  $\Delta H$ .

$$B - \Delta H = \$10,365$$

Benefit to Cost ratio:

$$\frac{B}{\Delta H} = \frac{\$11,350}{\$985} = 11.5$$





## APPENDIX C

BRIDGE RAIL SERVICE REQUIREMENTS<sup>(17)</sup>

1. A bridge rail system must laterally restrain a selected vehicle.
2. A bridge rail system must minimize vehicle decelerations.
3. A bridge rail system must smoothly redirect a colliding vehicle.
4. A bridge rail system must remain intact following a collision.
5. A bridge rail system which serves vehicles and pedestrians must provide protection for vehicle occupants and pedestrians.
6. A bridge rail system must have a compatible approach rail or other device to prevent collisions with the end of the bridge rail system.
7. A bridge rail system must define yet permit adequate visibility.
8. A bridge rail must project inside the face of any required curb.
9. A bridge rail system must be susceptible of quick repair.
10. The foregoing requirements must be met by giving emphasis first to safety, second to economics, and third to aesthetics.

