SOME CASE STUDIES OF HIGHWAY BRIDGES INVOLVED IN ACCIDENTS

M. H. Hilton, Virginia Highway Research Council

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. Several geometric characteristics were found to predominate at many of the arterial and primary system bridges investigated. Some of the more salient characteristics were pavement transitions on bridge approaches, approach roadway curvature to the left, narrow bridge roadway widths, intersections adjacent to bridges, and combinations of these and other geometric factors. On Interstate highway bridges, poor surface conditions were found to prevail during a significantly high proportion of accidents. Several case studies are presented that illustrate some of the characteristics of bridge sites that have been involved in highway accidents.

•BASED ON an average during the period 1966 to 1969 inclusive, 25.1 percent of the accidents on Virginia's Interstate, arterial, and primary highway systems were of the fixed-object type, whereas 30.9 percent of the deaths were associated with this accident type (1). As indicated from the data given in Table 1, one of the most formidable of the various types of fixed objects is the highway bridge. These data can be illustrated more vividly by expressing accident severity for any given year and type of highway system (or systems) in the form of a severity index. For any general accident category, we can define

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

where

SI = severity index,
D_p = proportion of persons killed, percent, and
A_p = proportion of all accidents, percent.

Thus, the relative severity of accidents involving highway bridges becomes more apparent, as is shown in Figure 1. In this figure the average severity of all accidents of all types on any given highway system would have an 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 occurring over the 4-year period illustrated.

To combat the severity of accidents involving structures, recent Virginia bridge designs have incorporated the General Motors type of safety parapet wall (2), wherein the approach roadway guardrail is anchored to the face of the wall at each end of the structure, and the full roadway shoulder width is carried across new bridges wherever possible. In addition, electronically controlled ice warning devices (3) have been installed at a number of hazardous bridge locations. In concert with this progress, a study was undertaken to identify some of the design and geometric features and other conditions, as noted in the Highway Safety Action Program (4, 5), that could possibly be related to the frequency or severity of accidents or both at bridge sites.

DATA SOURCES AND PROCEDURES

The following data sources were used in the study:

1. Standard form SR300 for Virginia State Police accident reports,
2. Questionnaire replies submitted by the six Virginia State Police divisions and the eight highway district offices,
3. Engineering and geometric data obtained from the original roadway plans for a select group of Interstate highway bridge sites involved in accidents during 1966, and
4. General physical and geometric data obtained from field inspections of a number of arterial and primary system bridge sites.

From the accident report data, a number of bridge sites were detected that had been the scene of several accidents during 1966. For those sites that appeared to have experienced an unusually high number of accidents, accident reports for subsequent years through 1969 were reviewed.

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 was that the respondent list those bridges in his area that, in his view, had been the scene of more than a normal number of accidents and that he 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.

From the information in the accident reports and the questionnaire replies, a list of bridge sites was compiled, and 30 arterial and primary system bridges were randomly selected for field inspection. In addition, a select group of Interstate bridges (those involved in more than two accidents during 1966) were studied separately by obtaining the engineering and geometric data from the original roadway plans.

EVALUATION OF QUESTIONNAIRE REPLIES

Table 2 gives the factors that 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) narrow bridge roadway, (b) curved approach roadway alignment, and (c) curved bridge alignment. It is interesting to note that the order of these factors in Table 2 is the same for each reporting group. Nearly half the bridges commented on 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 approximately a quarter of the sites commented on. 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.

More subtle factors such as approach roadway lane drops and transitions, intersections adjacent to bridges, and snow and ice 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 (e.g., bridge and guardrail) would be involved in accidents. Intersections and interchange ramp connections adjacent to bridges were also cited as constituting a hazard because the bridge railings obstruct vision, and entering and turning traffic increases the possibility of accidents involving collisions with the structure. Although the questionnaires that provided the information given in Table 2 were subjective in nature, substantial support from the work of others exists (7, 8, 9, 10, 11).

A general comparison of the two groups of questionnaire replies revealed several facts that might be expected but, nonetheless, are worthy of mention. First, on-the-scene accident investigation is one of the regular duties of police officers. Consequently, because of their experience, police officers would be more likely to recognize roadway factors that might contribute to accident frequency and/or severity than would most highway engineers. Second, the replying engineers recognized and reported many of the

Table 1. Percentage of accidents involving Interstate, arterial, and primary highway bridges in Virginia.

	Interstate Highways		Arterial and Primary Highways	
Year	Percentage of All Accidents	Percentage of All Persons Killed	Percentage of All Accidents	Percentage of All Persons Killed
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

Note: Data developed from statistics of Virginia Department of Highways (6).

Figure 1. Severity of accidents involving bridge structures and fixed objects.

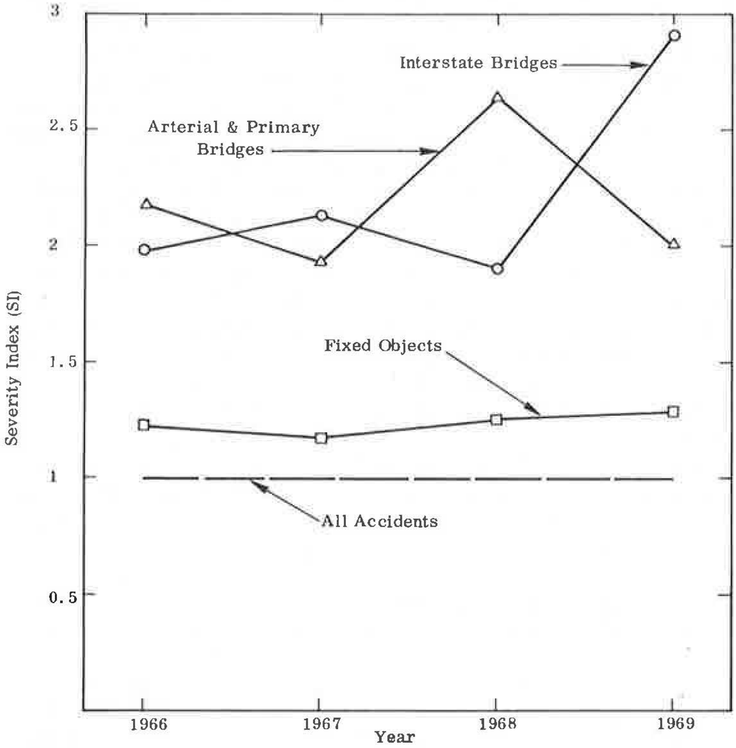

Table 2. Factors contributing to accidents at bridge sites.

	State Police Officers		Highway Engineers	
Contributing Factor	No. of Bridges	Percentage of Total Bridges Cited	No. of Bridges	Percentage of Total Bridges Cited[a]
Bridge roadway too narrow[b]	32	46	24	48
Curved approach roadway[b]	19	28	11	22
Bridge curved[b]	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[b]	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 and rough bridge	2	3	-	-
Pedestrian crossing on narrow bridge	2	3	-	-

[a] Percentage based on 50 sites commented on from a total of 79 sites listed by highway engineers.

[b] Combined effects of these factors were frequently cited.

bridge sites that 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.

ARTERIAL AND PRIMARY SYSTEM BRIDGES

General Geometrics

Along with the questionnaire replies, the accident reports for 1966 were used to compile a list of accident-prone locations. Field inspections were made of 30 bridge sites randomly selected from this list, and the alignment, grade, roadway widths, and so forth were noted for each bridge and its approaches. The four most prevalent geometric factors found at the locations were (a) downhill approaches, (b) narrow bridge roadway widths, (c) curved approach roadway, and (d) entrances or intersections adjacent to the bridge. The order of the dominant factors is much the same as that summarized from the state police questionnaire replies with the exception of downhill approach. Considering them as an individual element, Kihlberg and Tharp (7) found gradients to be less significant than factors such as curvature and intersections. Twenty-one percent of the accidents reviewed in the present study, however, occurred when snow and ice conditions existed, so it is probable that downhill gradients are often a contributing factor from this standpoint in addition to affecting vehicle speeds.

Fifteen (68 percent) of the structures with downhill approaches had approach roadway curvature, and 70 percent of those with approach roadway curvature had narrow bridge roadway widths. All three of these factors were present at 50 percent of the sites with downhill approaches. Thus, the high occurrence of combined geometrical factors at the sites surveyed appears to be significant because 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 highway bridges have intersections or pavement transitions immediately adjacent to them. Yet, intersections (or entrances) and pavement transitions were located at 43 and 13 percent respectively of the sites studied.

Findings similar to those discussed have been reported by Kihlberg and Tharp (7), who found that the presence of structures, curvature, gradients, and intersections generally has an increasing effect on accident rates. More significantly, they found that combinations of any of these elements generate higher accident rates than do individual elements.

Eighty-five percent of the study sites having approach roadway curvature had left-curved alignment in at least one direction of approach, whereas only 45 percent were curved to the right. Brown and Foster (10), in a study of bridge accidents in New Zealand, found that the right-curved approach alignment contributed to 3 times more accidents at the left approach and bridge end post than did left-curved alignment. Because New Zealanders drive on the left side of the road, the analogous situation in the United States would be for more accidents to occur on left-curved approaches. 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 to experience high accident rates (8, 9). Brown and Foster (10) found that 70 percent of the accidents occurred where the ratio of the bridge roadway width W_B to the approach roadway width W_R (including the shoulder width) was ≤ 0.79. A similar ratio could be determined on 19 of the sites surveyed in this study. Seventeen, or 90 percent, of these had W_B/W_R ratios of less than 0.79. Sixteen, or 84 percent, had ratios less than 0.69.

Case Studies

Discussion of some study examples serves the following purposes:

1. Indicates the general types of accidents that occur at some typical accident-prone bridge sites,
2. Explores possible safety improvements at some of these locations, and
3. Illustrates how on-the-site field inspections supplemented by accident report information can sometimes reveal roadway factors that could contribute to accidents.

Case Study 1—The first case study bridge has had a history of accidents, one fatal, and was recently involved in a sequence of collisions. When a bridge with a narrow roadway width is located within a passing opportunity section of a two-lane highway such as that shown in Figures 2 and 3, 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 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, 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 rail. 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. 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 by an out-of-control eastbound vehicle. The last two accidents were single-vehicle property damage types in which the driver lost control after running off the edge of the pavement in the area of the intersection adjacent to the bridge. Note also that there is no pavement edge striping 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 because 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:

Item	Cost (dollars)
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	1,728
Total	5,728

The handrails were repaired by state forces. If medical costs, lost wages, etc. were included in this estimate, the total economic losses would, of course, have been higher.

Case Study 2—The second case study bridge was very similar to the first. It too was located on a two-lane highway in a passing opportunity area and had a narrow roadway width. Several accidents and one fatality have resulted from collisions at the site in recent years. This 32-ft long structure, however, was recently widened from a 23- to a 40-ft roadway width at a cost of $17,000 (cost of work performed by state forces).

Curves that 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 (12) and are shown in Figures 4 and 5. By extrapolating the curve D = 0 of Figure 4, we can estimate that an average reduction in accidents of approximately 95 percent can be expected from the 17-ft widening of the second case study structure. A similar reduction in property damages and injuries could be expected by extrapolation of the curves shown in Figure 5. Benefit and cost estimates can be calculated for the widening improvement by using the methodology presented by Jorgensen (12). Thus, for an annual cost of $985 (based on a 30-year service life), widening of the bridge will yield estimated average annual benefits of $11,350 for a benefit-cost ratio of 11.5 (1). Inasmuch as these two case study structures are quite similar, the first bridge could be widened for approximately the same cost as the second. The annual cost of such an improvement to the first structure would be less than one-fifth of the $5,728 property-damage estimate for the recent series of accidents.

Installation of guardrail in lieu of widening at either of these two bridges would probably not reduce the number of accidents. Also, maintenance costs for repairs would likely remain high if such an alternative were selected. Again using the same forecasts and methodology (12), we can estimate that the average annual benefits to be derived from a guardrail installation would be $2,520, whereas the annual cost would be $433. This yields a benefit-cost ratio of 5.8 (1). 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 should not be confused with the need to reduce the severity of collisions with structures typical of the one shown in Figures 6 and 7. In the latter type of situation, many older bridges that constitute potential fixed-object hazards should be upgraded to comply as nearly as possible with at least the following three of 10 bridge rail service requirements developed by Olson et al. (11):

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

Progress toward meeting these requirements can be made. In Figure 8, 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 when the continuous guardrail is anchored to the existing bridge rail. Similar rail systems have been described by Tutt and Nixon (13).

Case Study 3—Slowing, stopping, or turning traffic at intersections, business entrances, and so forth increases accident potential. When bridges happen to be located adjacent to points of high accident potential, their potential for involvement also appears to be increased. A typical example is shown in Figure 9 in which a bridge with a narrow roadway is located adjacent to an intersection where traffic slows or stops for left turns. Collisions with the right bridge rail have resulted from situations in which a vehicle has maneuvered 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.

Case Study 4—In the next case study, seven fatalities resulted from two single-vehicle collisions with the right end post of the bridge rail 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. As one approaches the bridge (Fig. 10), 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. If we consider 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 end post. 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 end post even though 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 all could have been contributing factors in these accidents.

Case studies 3 and 4 suggest that intersections should be located as far away from bridge sites as possible. 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.

Case Study 5—Each approach to this case study bridge (Fig. 11) 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

Figure 2. A narrow bridge located within a passing opportunity section of two-lane highway with intersection to the right adjacent to the structure.

Figure 3. Same bridge shown in Figure 2 with east end of north rail knocked out.

Figure 4. Forecast chart of accident reduction through bridge widening (12).

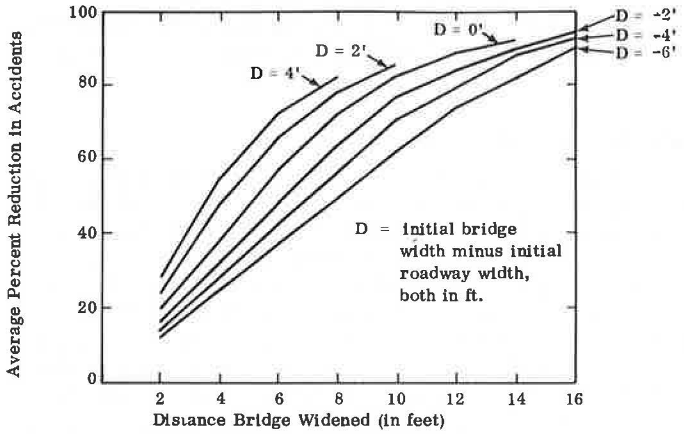

Figure 5. Forecast chart of fatality-injury and property damage reduction through bridge widening (12).

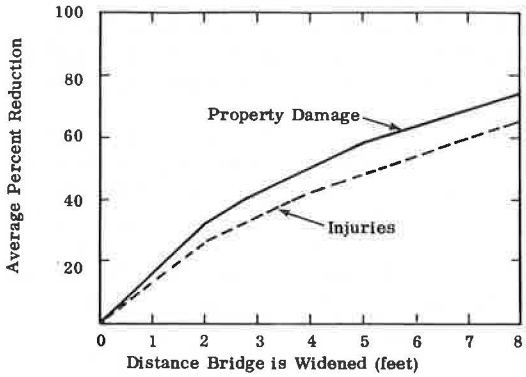

Figure 6. Restricted roadway width and exposed ends of rigid concrete railing.

type of practice, as prior studies have shown (9, 12, 14), 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 and off the bridge; the driver was killed. 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 the one illustrated.

Each of the last two examples demonstrates the general finding that pavement transitions on bridge approaches should be avoided. When transitions are necessary, 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.

Case Study 6—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 12, a bridge on which several skidding accidents occurred during wet surface conditions. Significant portions of the deck had been repaired with an epoxy surfacing material that had not been treated with a deslicking grit (sand) during the initial application. McKeel (15) 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 to become very slick.

INTERSTATE HIGHWAY BRIDGES

For 27 bridge sites that had two or more accidents during 1966, a summary of certain approach roadway geometrics and accident data was tabulated. Sixteen of the sites have curved approaches, 13 of these being 1 deg or less. Twenty-three of the sites have downhill approaches, and generally the higher the percentage of grade is and the higher the degree of curvature is, the greater will be the relative percentage of accidents during wet surface conditions. Approximately 50 percent of the accidents occurred when the bridge deck surface was either wet, snowy, or icy, whereas, for comparison, these conditions existed in 31 percent of all accidents on the total Interstate system during 1966 (6). Of 42 individual bridges involved in two or more accidents in 1966, 62 percent are approached by a downhill grade of 1,000 ft or more in length. An additional 24 percent have downhill approach lengths of between 500 and 1,000 ft. Thus, the most dominant factor in the Interstate highway bridge accidents appears to be adverse surface conditions, particularly when long, steep approach grades are present.

At one Interstate highway bridge site, six of 17 accidents reviewed for the period 1963 to 1967 involved icy conditions on the bridge deck. These two structures are approached on the northbound lane by a 1.4 percent downhill grade of approximately 1,600 ft in length and on the southbound lane by a 3.5 percent downhill grade of approximately 600 ft in length. Superposition of icy deck conditions on the long and relatively steep downhill approaches could explain part of the high accident rate at this location.

Of all Interstate highway bridge accidents in 1966 that were reviewed, 33 percent occurred under icy or snowy (excluding wet) surface conditions. The comparable figure on primary and arterial system bridges was 21 percent. The higher percentage on the Interstate highway bridges suggests that the freer traffic flow and higher speeds on Interstate highways contribute to higher accident rates during icy and snowy conditions. Either many drivers apparently are not aware of the fact that, when moisture is present during freezing temperatures, ice will form on bridge decks before it does on the roadway, or they are not making adequate speed adjustments for poor surface conditions.

It was difficult to evaluate the bridge-approach roadway relationships on all of the bridge sites investigated due to variations in ramp intersections at interchanges. At 19 of the sites, however, it was found that 63 percent of the most accident-prone Interstate highway bridges had clear roadway widths of 28 to 30 ft, whereas the remaining 37 percent were 40 to 42 ft. Seventy-four percent of the sites had a bridge-approach

Figure 7. Head-on collision with right end post of bridge shown in Figure 6.

Figure 8. Approach guardrail continued across a bridge.

Figure 9. Bridge with narrow roadway located adjacent to intersection (center) and business entrance (right foreground).

Figure 10. Bridge located at end of pavement transition from two to four lanes.

Figure 11. Transition from four to two lanes on approach to major bridge crossing.

Figure 12. Site of several skidding accidents on downhill, superelevated deck treated with epoxy surface treatment with no initial deslicking sand applied.

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 than those with greater ratios.

SUMMARY

1. Probably because accident investigation is one of their regular duties, state police officers are more likely to recognize the more subtle roadway factors that might contribute to accident frequency and/or severity at bridge sites than are most highway engineers.

2. Some of the engineers replying to the study questionnaire appeared more inclined than did the state police 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 felt to contribute to accidents at bridge sites.

3. 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 accident histories. These factors are (a) narrow bridge roadway width—accident potential appears to be high 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 more dominant factor than curvature to the right; (c) pavement transitions on bridge approaches—transitions from four to two lanes and vice versa on bridge approaches appear to increase the potential for accidents involving components of the bridge; (d) intersections adjacent to bridges; (e) downhill approach gradients; (f) bridge curvature; and (g) combinations of any of these factors.

4. The severity of accidents at many of the relatively old bridges could probably be reduced by installing approach guardrails that either are effectively anchored to the existing bridge rail or continue across the full length of the bridge.

5. An analysis of a single-span bridge with a narrow roadway width that has been widened suggests that widening would yield favorable benefit-cost ratios for similar structures having accident histories.

6. On two-lane highways, narrow bridges that are located within passing opportunity sections appear to have a high potential for being involved in accidents.

7. Many bridge railings will not restrain a standard-sized vehicle, nor will they remain intact following a collision.

8. The discontinuation of main roadway pavement edge striping at intersections adjacent to bridges may be misleading or confusing to motorists approaching them under certain adverse environmental or physical conditions.

9. Intersections and entrances adjacent to bridge sites appear to increase the potential for collisions. Factors apparently involved include obstruction of view due to the bridge railings, increased traffic conflicts at the fixed-object location, and, under certain conditions, confusion on the part of motorists.

10. The most dominant factor in the 1966 Interstate highway bridge accidents studied was adverse surface conditions (wet, snowy, or icy), particularly when long, steep approach grades are present.

11. A larger proportion of accidents (33 percent of the accidents studied in 1966) occur on Interstate highway bridges when icy or snowy surface conditions exist than on primary system bridges (21 percent of the accidents studied). This suggests that many motorists are not making adequate speed adjustments for poor surface conditions on high-speed highway bridges.

REFERENCES

1. Hilton, M. H., and Redick, J. R. A Study of Accidents Involving Highway Bridges. Virginia Highway Research Council, March 1971.
2. Lundstrom, L. C., Skeels, P. C., Englund, B. R., and Rogers, R. A. A Bridge Parapet Designed for Safety. Highway Research Record 83, 1965, pp. 169-187.
3. Operation of the Ice Condition Detection System. Holley Carburetor Co., Warren, Mich., 1966.

4. Highway Safety Action Program—Engineering Section. A report of the President's Committee for Traffic Safety, 1966.
5. Highway Safety Action Program—Research Section. A report of the President's Committee for Traffic Safety, 1966.
6. Summary of Accident Data, State Highway Systems. Virginia Dept. of Highways, 1966, 1967, 1968, 1969.
7. Kihlberg, J. K., and Tharp, K. J. Accident Rates as Related to Design Elements of Rural Highways. NCHRP Rept. 47, 1968.
8. Traffic Control and Roadway Elements—Their Relationship to Highway Safety. Automotive Safety Foundation, 1963.
9. Gunnerson, H. E. Iowa Narrow Bridge Accident Study. Iowa State Highway Commission, 1961.
10. Brown, J. V., and Foster, J. Bridge Accidents on Rural Highways in New Zealand: Analysis and Appraisal. Proc., Third Conf. of Australian Road Research Board, Vol. 3, Pt. 1, 1966, pp. 638-646.
11. Olson, R. M., Post, E. R., and McFarland, W. F. Tentative Service Requirements for Bridge Rail Systems. NCHRP Rept. 86, 1970.
12. Evaluation of Criteria for Safety Improvements on the Highway. Roy Jorgensen Associates and Westat Research Analysts, Inc., 1966, pp. 49-50, 151-152, 194-200.
13. Tutt, P. R., and Nixon, J. F. Roadside Design Guidelines. HRB Spec. Rept. 107, 1970.
14. Williams, S. J., and Fritts, C. E. Let's Build Safety Into Our Highways. Public Safety, May 1955, pp. 22-23.
15. McKeel, W. T. An Evaluation of Epoxy Compounds as a Material for Patching and Protecting Concrete. Virginia Highway Research Council, March 1971.