Effect of Bridge Width on Highway Safety

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In 1983, 44 percent of the nation's 550,000 highway bridges were reported to be deficient in one or more ways. Structural condition and deck geometry were considered the most pervasive deficiencies *(1)*. Deck geometry was reported the primary deficiency for 34,135 (12.7 percent) bridges on arterial and collector highways, most of which have widths narrower than the approach roadways.

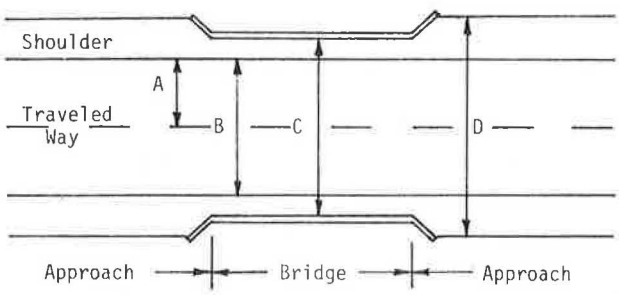
Mak and Calcote *(2)* found that the number of bridge-related fatal accidents per 100 million vehicle miles of travel was significantly higher than average for all road types. The number of bridge-related nonfatal accidents per 100 million vehicle miles of travel were also higher than average for Interstates and rural arterials and collectors, but lower for urban arterials and collectors. Hilton reported that the fatality rate for bridge-related accidents was roughly two times that of the average accident *(3)*. It is evident that a safety problem does exist with bridges in general, especially those on Interstates and rural highways.

Bridge width, both absolute and relative, has long been considered a major factor affecting safety at bridge sites. Ideally, the bridge width should be at least the same as the approach roadway width from a safety standpoint. However, the costs associated with bridge structures are very high in comparison to a normal roadway section, especially for long-span structures. In terms of costs, it is economically prohibitive to upgrade all existing bridges to the full approach roadway width. Some trade-off is therefore necessary, particularly for minor roadways with low traffic volume.

A critical review of available literature on the safety effects of bridge width was conducted as part of a Transportation Research Board study on geometric design standards for resurfacing, restoration, and rehabilitation (RRR) projects on non-Interstate highways. The results of the literature review and synthesis are presented in this paper.

RESEARCH FINDINGS: BRIDGE WIDTH VERSUS SAFETY

In presenting the results of past research, studies are categorized as those that *(a)* use surrogate measures, *(b)* evaluate safety at bridge sites in general, and *(c)* specifically evaluate the safety effect of bridge width. Some studies are in more than one of these categories. Pertinent portions of these studies are reviewed separately under the appropriate category. Also, to assure uniformity of definitions, the key elements at a bridge site are shown in Figure 1.



where A = Lane Width,

B = Traveled Way Width,

C = Bridge Width,

D = Approach Roadway Width,

RW = Relative Bridge Width

= Bridge Width - Traveled Way Width; or (C -B)

FIGURE 1 Key elements at bridge site.

Surrogate Measures Studies

A number of studies have been conducted on driver behavior at bridge sites *(4–6)*. In a 1941 study Walker reported on 11 bridge sites on two-lane, two-way rural highways (9 in Maryland and 2 in Oregon) *(4)*. Data were collected on lateral positions of more than 20,000 vehicles traversing the bridges at these sites, on both straight and level sections of highway.

A West Virginia study on driver behavior involved both an experimental and a field study *(5)*. In the experimental study, 10 subjects were asked to drive an instrumented car over a mock-up two-lane, two-way, 50-ft-long bridge 30 times for each increment of bridge width from 16 to 48 ft. All tests were conducted during daylight hours. A variety of data were collected, including steering wheel reversals and vehicle lateral placement. In the field study, the shoulder width of a two-lane, one-way bridge on an Interstate highway was varied from 2 to 10 ft using mock-up curb and guardrail. Two hundred passenger cars traversing the bridge were monitored for speed and lateral placement for each shoulder width. Again, the data were collected only during daylight hours and under fair weather conditions.

Ivey et al. collected vehicle speed and lateral placement data for more than 2,000 vehicles at 25 bridge sites on rural two-lane, two-way highways in 7 states *(6)*. The

characteristics of the bridge sites, as in the Walker study *(4)*, varied widely, with different bridge and approach roadway widths, lengths, traffic volumes, and bridge structure types—from truss to open deck design.

The following conclusions were drawn from the studies on driver behavior:

1. Vehicle speed was affected very little by bridge width, but was more a function of other bridge and approach characteristics, such as vertical alignment *(4–6)*.
2. Walker *(4)* concluded that drivers tended to maintain a more or less uniform distance between their right wheel and the curb or parapet of the bridge, which resulted in a lateral movement of the vehicles toward the left if the bridge was narrower than the approach roadway. This distance varied by bridge width, time of day, and whether the vehicle was free-moving or meeting another vehicle. Other factors that influenced driver behavior included the presence or absence of centerline stripes, truss versus deck design, and bridge length. Ivey et al. reported that the lateral movement was a function of both the absolute and relative bridge widths *(6)*.
3. Under the more critical condition of meeting another vehicle, Ivey et al. *(6)* found that the drivers tended to maintain approximately the same clearance between their vehicle and the opposing vehicle to the left and between their vehicle and the curb or parapet of the bridge to the right.
4. In the instrumented vehicle study *(7)*, shoulder widths of 4 to 6 ft were found to result in the lowest number of steering wheel reversals and the greatest lateral distance between the left wheel of the vehicle and the centerline.
5. Walker *(4)* reasoned that, for complete freedom of movement on a bridge, one-half of the bridge width should equal to the sum of one-half the clearance allowed between vehicles while meeting on the highway, the width of the vehicle (assumed to be 5 ft), and the clearance to the curb or parapet of the bridge under free-moving condition.

The biggest problem encountered in these studies that used surrogate measures is that there is no established linkage that would allow the results to be related to accidents. Also, only passenger cars were included in these studies; no consideration was given to trucks, which have greater widths. Nevertheless, logical relationships, such as those developed by Walker, can be of some use. For example, assuming that a minimum of 6 ft is desired from the right wheel of the vehicle to the curb or bridge rail (a range of 4.2 to 7.4 ft was reported by Walker), a vehicle width of 5 ft, and the distance from the left wheel of the vehicle to the centerline is 3 ft (i.e., one-half of the clearance between opposing vehicles that Ivey found to be roughly the same as the clearance to the curb or bridge rail), the minimum bridge width should be 28 ft, which is twice the sum of 6 + 5 + 3 = 14.

General Bridge Safety Studies

Safety at bridge sites has long been an area of concern and the subject of numerous studies *(3, 8–10)*. All of these studies pointed to the hazard of narrow bridges, but were mostly descriptive in nature and did not provide sufficient data to establish the relationships between bridge width and accidents.

In 1955 Williams and Fritts *(8)* reported that, based on an analysis of accident data from 10 states, the accident rate was 1.0 accident per million vehicles for bridge structures with widths of 1 ft or more narrower than the approach roadway width, 0.58 for widths of between 1 ft narrower and 5 ft wider, and only 0.12 for widths of 5 ft or more. No detail was provided on how these figures were compiled.

In 1966 Hilton identified bridges in Virginia on which an unusually high number of accidents had occurred *(3)*. Thirty bridges on arterial and primary system highways were randomly selected for study from the list of bridges identified. Another 27 bridge sites on Interstate highways on which two or more accidents had occurred during 1966 were also selected for study. Narrow bridge width, curved bridge and approach roadway alignment, and downhill approaches were found to be the most prevalent characteristics at the 30 arterial and primary system bridges. The ratio of bridge roadway to approach roadway width was determined for 19 of the bridges, 17 (89.5 percent) of which had ratios of less than 0.8, and 16 (84.2 percent) of which had ratios of less than 0.7. Adverse surface condition was reported as the most prominent factor responsible for accidents on the high-accident Interstate bridges. Furthermore, nearly two-thirds (63 percent) of these bridges had clear widths of only 28 to 30 ft, whereas 74 percent of the sites had a bridge-to-roadway width ratio of less than 0.8. Unfortunately, no data were available for comparison purposes on bridges with lower accident experience.

In a study of accident statistics for Kentucky during 1972 and 1973, Agent reported that approximately 35 percent of bridges on Interstates and parkways had full-width shoulders and accounted for only 10 percent of bridge accidents *(9)*. Also, none of the nine bridges identified as high-accident sites (seven or more accidents in the 2-year study period) had full-width shoulders. For bridges on primary and secondary highways, none of the 11 bridges identified as high-accident sites (three or more accidents in 1972) had wide shoulders.

Similar findings were reported in an Australian study by Brown and Foster *(10)*. Nearly 70 percent of bridge accidents (single-vehicle accidents that occurred on bridges and their approaches) during 1961–1962 occurred on bridges where the bridge-to-approach roadway width ratio was less than 0.8 ft; only 14 percent occurred on bridges with full approach width.

A series of studies have been aimed at developing a bridge safety index (BSI) that would serve as an indicator of the degree of hazard associated with a bridge and as a means to priority rank bridges for corrective treatment *(6, 7, 11, 12)*. The BSI, as first developed by Ivey et al. *(6)*, is the sum of 10 individual rating factors. Three of the factors are related to bridge width: *(a)* bridge clear width, *(b)* ratio of lane width on bridge to that on approach roadway, and *(c)* percent shoulder reduction. A field evaluation form and accompanying instruction procedures were developed for use by highway department personnel *(11)*.

Two additional rating factors were later added to the BSI to provide an indication of the presence of safety treatments; that is, delineation and signing at the bridge sites *(7)*. Bridge, roadway, and accident (1978–1979) data were collected and analyzed on 78 bridge sites in Texas where corrective measures were recommended in an effort to validate the BSI. The data were further analyzed statistically by using logistic regression to develop a better and more objective BSI *(12)*.

The BSI is an intuitively appealing concept that allows the relative safety or hazard of bridges to be expressed by using a single index. The rating factors were initially developed subjectively on the basis of "engineering judgment" with no attempt to test and validate the index. Mak and Calcote tested the BSI using accident data and found that it was not a good indicator of safety at bridges. Similar results were reported in follow-up studies to improve on the original BSI *(7, 12)*. However, the results of these follow-up studies are likely to be biased because the 78 bridge sites studied were not representative of the bridge population; that is, these bridge sites had been recommended for corrective treatment, which would mean that they either had high accident experience or were perceived as hazardous.

Bridge width, the first rating factor of the BSI, was found to be significantly related to accident rates in all these studies *(2, 7, 12)*. However, the results are of little use because the bridge width term was either expressed as a rating or was part of a statistical model with poor predictive ability.

Accident Studies on Bridge Width

Few studies have been specifically designed to address the safety effects of bridge width *(2, 13–16)*. These studies were all of the cross-sectional (comparative evaluation) design except for the study by Gunnerson *(13)*, which used a retrospective before-and-after design.

Gunnerson studied the accident data on 72 narrow, rural two-lane bridges in Iowa over a 12-year period from 1948 to 1959 *(13)*. Of the 72 bridges studied, 65 had widths less than 24 ft, which remained unchanged while the approach pavements were widened to 24 ft. The remaining seven bridges had both the bridge and approach roadway width widened to 30 ft and were used for control purposes. Comparisons were made between the number of total accidents, number of bridge hits, injuries, and amount of property damages in the before and after time periods. To account for differences in the amount of time in the before and after periods, the accident frequencies were adjusted to be on a per month basis. No adjustment was made for any change in traffic volume on these bridges although the data were divided into separate average daily traffic (ADT) groups for analysis.

It was concluded that accident frequencies increased sharply when only the approach roadway pavement width was widened and not the bridge width or, conversely, when the approach traveled way width was wider than the bridge width. When both the approach roadway and bridge were widened to the same width, the accident frequency decreased. The study design suffered from the lack of control sites for comparison purposes. The seven bridges used as control sites actually received a different treatment, and the comparison was more that of differences between the two treatments. With a long study period of 12 years, changes to the bridge or approach roadway widening, or both, were likely to have occurred, which could affect accident frequencies, especially when no adjustment for traffic volume changes was made. Despite the drawbacks to the study design, the results illustrated that the bridge width should, at the very minimum, be as wide as the approach traveled way width.

Cirillo reported on the effect of lateral clearance (distance from edge of traveled way to bridge rail) at bridge structures on accident frequency and severity *(14)*. The accident data covered a 3-year period from 1961 to 1963 and approximately 2,000 mi of Interstate highways in 16 states. Accident rates were tabulated for various combinations of structure length and lateral clearance. Cirillo concluded that increase in minimum lateral clearance would reduce accident rates. Also, as the structure length increased, the need for larger lateral clearance was indicated by the increase in the accident rate. Similar tabulations were compiled for accident severity, expressed in terms of property damage costs. The results are not too meaningful, however, because property damage cost is not a good indicator of occupant-injury severity.

A somewhat different conclusion can be drawn from the data by combining some categories of bridge lengths, as shown in Figure 2. For structures with lengths up to 300 ft, the accident rates decreased sharply when the lateral clearance increased from less than 6 ft to 6.0–8.9 ft, but remained little changed or actually increased slightly when the lateral clearance was further increased to 9.0–12.9 ft. For the longer structures, the accident rates continued to decrease with an increase in lateral clearance. This appears

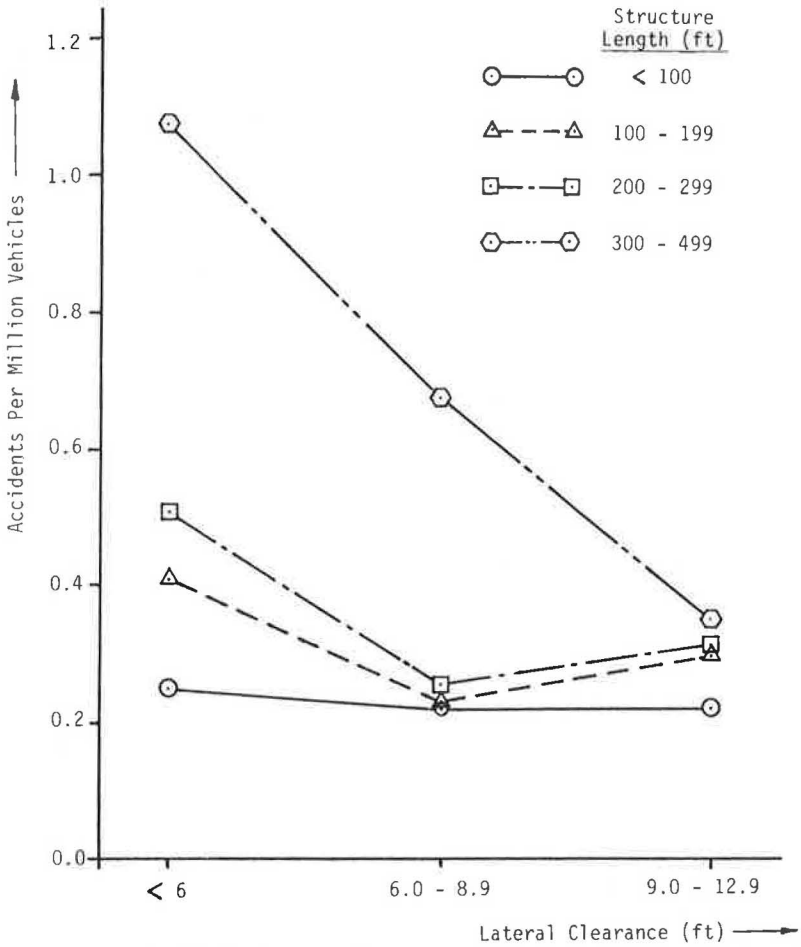


FIGURE 2 Accident rate per million vehicles by structure length and lateral clearance (14).

to indicate that, for structures with lengths up to 300 ft, the minimum lateral clearance should be no less than 6 ft, but little safety benefits are gained by increasing the lateral clearance to more than 9 ft. As for longer structures, it is desirable to have as great a lateral clearance as possible. It should be noted that the values of 6 and 9 ft are artifacts of the data grouping and not necessarily the critical values.

In a study of 58 bridges on Interstate highways in Colorado *(15)*, comparisons of total, nonfatal injury, and fatality rates (accidents per 100 million vehicles) for bridge-related accidents over a 4-year period (1968 to 1971) were made between twin structures with widths of 30 and 38 ft. The study concluded that twin structures 38 ft wide (full approach shoulders of 10 ft right and 4 ft left) were almost four times safer than those 30 ft wide (only 6 ft of shoulder total).

The Colorado study also included a representative sample of 219 structures on rural, two-lane primary highways. Accident rates were purported to be related to *(a)* bridge width; *(b)* relative bridge width (i.e., structure width minus approach traveled way width); and *(c)* bridge shoulder width versus approach roadway shoulder width. However, no statistical analysis was presented.

Of the 219 structures, only 58 experienced one or more accidents during the 4-year study period for a total of 94 accidents. Accident rates by bridge widths and by relative

bridge widths are given in Tables 1 and 2. Least-squares quadratic curves were fitted to the data and are shown graphically as Equations 1 and 2 in Figures 3 and 4, respectively. The minimum accident rate according to the curves is at a bridge width of 30.5 ft or when the structure width is approximately 6 ft wider than the approach traveled way width.

TABLE 1 Accident Rate by Bridge Width *(15)*

Bridge Width (ft)	No. of Structures	No. of Accidents	Average ADT	Accidents per Million Vehicles
19	3[a]	1	250	0.91
20	2[a]	10	1,975	1.73
23	1[a]	1	1,350	0.51
24	15	12	1,179	0.46
25	57	21	787	0.32
28	27	5	1,051	0.12
29	24	4	1,325	0.09
30	78	39	1,721	0.20

[a]This data point has a sample size of less than five and is not used in the reanalysis.

TABLE 2 Accident Rate by Relative Bridge Width *(15)*

Relative Width (ft)	No. of Structures	No. of Accidents	Average ADT	Accidents per Million Vehicles
<0[a]	5[b]	11	940	1.60
0[a]	8	8	1,286	0.53
1	9	12	1,581	0.58
2	6	4	1,490	0.31
3	38	7	752	0.17
4	4[c]	0	340	0.00
5	15	4	879	0.21
6	48	20	1,865	0.15
7	18	2	1,160	0.07
8	49	22	1,368	0.22
>8	19[b]	4	1,069	0.13

[a]Narrow bridges having no paved shoulders.
[b]This data point is not used in the reanalysis because the boundary for the interval is not defined.
[c]This data point has a sample size of less than five and is not used in the reanalysis.

There were 55 structures with full-approach shoulder width, and the average accident rate was 0.20 accidents per million vehicles, which was 20 percent lower than the accident rate of 0.24 accidents per million vehicles for the 164 structures without full-approach shoulder width.

The study concluded that the optimum bridge width should be the greater of 30.5 ft, 6 ft wider than the approach traveled way width, or carrying the full approach shoulder.

The study results should be viewed with caution because the data were collapsed into one-way tables for analysis, which could mask or confound the effects of other

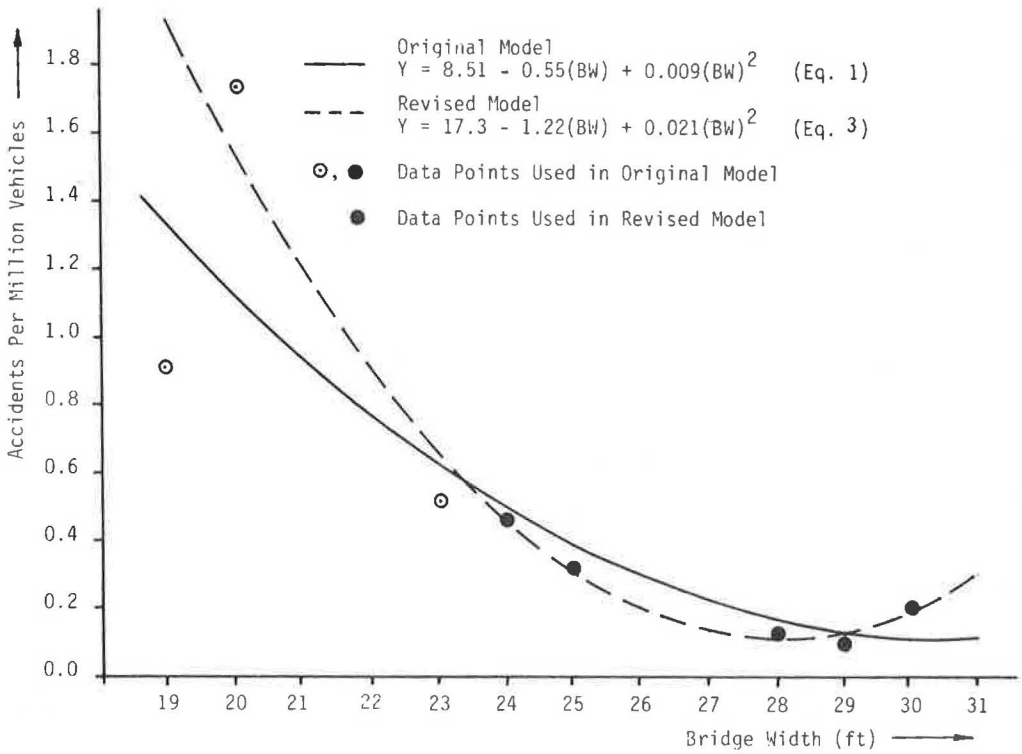


FIGURE 3 Accident rate by bridge width (15).

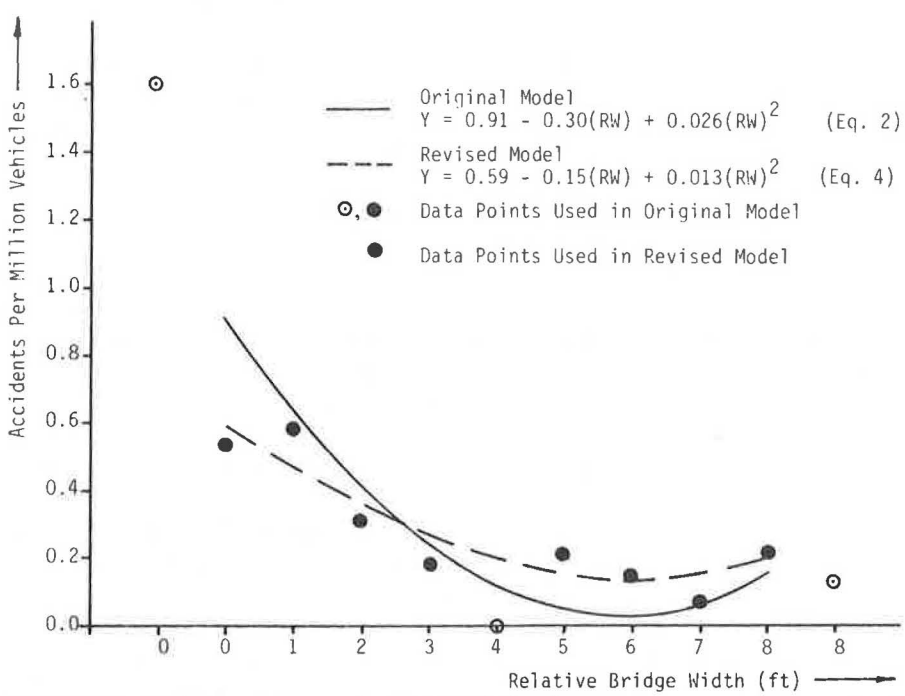


FIGURE 4 Accident rate by relative bridge width (15).

influencing factors on accident rates. The sample sizes were very small for some of the bridge widths or relative bridge widths, and the calculated accident rates could be somewhat unstable. Also, no statistical testing was attempted with the analyses.

To overcome the concern of unstable accident rates due to small sample sizes, data from categories of bridge widths or relative bridge widths with less than five structures are eliminated and the data reanalyzed. Again, least-squares regression models are fitted to the data, and the revised curves are shown graphically as Equations 3 and 4 in Figures 3 and 4, respectively, together with the original curves. It should be noted that the revised curves are based on a small number of data points (shown as solid circles in Figures 3 and 4).

In general, the reanalysis does not substantially alter the conclusions except that the minimum accident rate occurs at a bridge width of 28 ft instead of 30 ft. As for relative bridge width, the minimum accident rate occurs at a relative bridge width of 6 ft in both cases.

In a more recent study by Mak and Calcote (2), computerized data files on bridge inventory and accidents (1975–1977) from five states were used to create a data base for study. Accidents were matched to the bridges and their approaches (500 ft for each approach) through a milepoint matching process. The final data base contained bridge, roadway, traffic, and accident data on 11,880 bridges with 24,809 associated accidents. A stratified random sample of 1,989 bridges was then selected for manual collection of data to supplement the computerized data. A variety of analyses were conducted in an effort to relate accident frequency (accidents per year per bridge), rate (accidents per million vehicles), and severity (average cost per accident) to the bridge, approach, operational, and countermeasure characteristics of the bridge sites.

The study revealed that for two-lane single structures the accident rate generally decreased with increasing bridge width for those bridges narrower than the approach roadway. However, for those bridges that were wider than the approach roadways, the highest accident rates were at bridge widths of between 20 and 22 ft. For structures under 24 ft wide, the majority of the bridges either had no approach shoulders or shoulder reduction on the bridges. The percentage of bridges on which accidents occurred and the accident rates were much lower for bridges with no shoulder reduction or no approach shoulders. For structures wider than 24 ft, the percentage of bridges on which accidents occurred and the accident rates were highest for bridges with more than 50 percent shoulder reduction, and both decreased with less shoulder reduction.

For two-lane twin structures, bridges with widths of 24 ft or less and those with greater than 50 percent shoulder reduction had similarly high accident rates. The accident rates decreased significantly for bridges with 1 to 50 percent shoulder reduction and remained almost unchanged for bridges with no shoulder reduction. This suggests that there is little difference in safety benefits between bridges with no shoulder reduction or 1 to 50 percent shoulder reduction.

As for accident severity, shoulder reduction appeared to have some marginal effect on twin structures, with higher accident severity for bridges with greater than 50 percent shoulder reduction. Otherwise, bridge narrowness appeared to have no effect on accident severity.

Mak and Calcote (2) evaluated the safety effects of absolute or relative bridge width categorically in terms of no approach shoulder, greater than 50 percent shoulder reduction, 1 to 50 percent shoulder reduction, and no shoulder reduction. Results of statistical analyses in which accident frequency, rate, and severity were related to bridge width, shoulder reduction, and other bridge, roadway, and traffic characteristics were generally weak. However, the results did illustrate that bridge width was only one of many factors influencing accident rates at bridge sites.

Turner used bridge, roadway, and accident data on rural two-lane highways in Texas to predict bridge accident rates *(16)*. The sample consisted of 2,849 bridge-related accidents on 2,087 bridges over a 4-year period from 1975 to 1978. After some preliminary analyses, three variables—ADT, approach roadway width, and bridge relative width—were selected for further analysis. ADT was then dropped from the analysis because it was already included in the determination of accident rate, expressed as the number of accidents per million vehicles. A 99-cell matrix of 9 approach roadway widths and 11 bridge relative widths was formed, and the accident rate per million vehicles was calculated for each cell.

Plots of accident rate by bridge relative width for each approach roadway width category displayed a similar trend of high accident rates at small relative widths that decreased with increasing relative width. Also, approach roadway width was found to be nonsignificant in the regression analysis and was dropped from further consideration. The data were then combined for all approach widths, and accident rates were regressed against bridge relative widths using weighted regression analysis. The resulting weighted regression equation is as follows and the curve is shown in Figure 5:

$$Y = 0.50 - 0.061\,(RW) + 0.0022\,(RW)^2 \qquad (5)$$

where Y is the number of accidents per million vehicles, and RW is the bridge relative width in feet.

At relative widths of 6 ft or wider, the curve remained fairly flat with an accident rate of between 0.07 and 0.2 accidents per million vehicles. For relative widths of less than 6

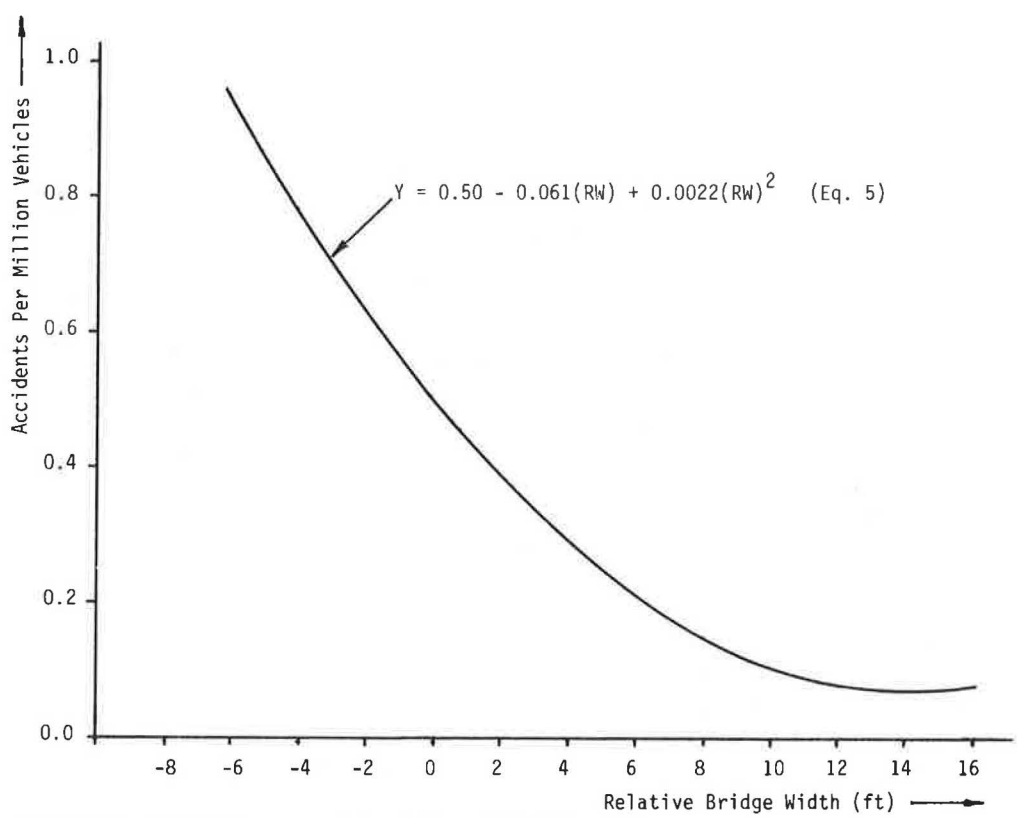


FIGURE 5 Accident rate by relative bridge width (16).

ft, the curve had a steep slope, indicating a rapidly increasing accident rate with decreasing relative widths. The results suggest that a minimum of 3-ft-wide shoulders should be provided for bridges on rural two-lane highways; wider shoulders would be of little additional safety benefit.

The study has some problems, such as the reliability of accidents identified as bridge-related in the accident reports. There is some concern over the small sample size for very narrow or very wide bridges because more than 98 percent of the bridges are located on roadways 18 to 26 ft wide, as illustrated by the drastic difference between the two equations. Also, there is the question of the effect of responsible factors other than bridge width.

In both the Colorado *(15)* and the Turner *(16)* studies, the best fitting models are quadratic curves so that a minimum accident rate occurs at some bridge width or relative bridge width. One question that arises is whether the upturn in the curves is an artifact of the curve-fitting procedure or a true indication that accident rates would increase if the bridge width or relative bridge width is increased to beyond the optimum (i.e., the width with the lowest accident rate). Intuition would suggest that the accident rate should continue to decrease with increasing bridge width or relative bridge width, and the concept of an optimum bridge width or relative bridge width is not supportable. However, the data suggest the contrary.

Similar trends are found in several studies *(2, 14–16)* indicating that there is little change or even slight increase in the accident rate when the bridge width or relative bridge width is increased to beyond a certain point. There are no apparent explanations for such an upturn in the accident rate, and there is simply insufficient information available from the literature to answer this question more thoroughly. The best guess is that there may not necessarily be an optimum bridge width or relative bridge width that has the minimum accident rate. Nevertheless, there is sufficient evidence in the literature to suggest that there is a certain bridge width or relative bridge width beyond which the incremental safety benefit would be minimal.

The results of some of the preceding studies on bridge safety have been synthesized in a number of reports *(17–20)*. Most of these syntheses simply reported the relationships developed from previous studies or used the relationships for their own applications. The relationships were accepted at face value without any critical review. One exception is the study by Jorgensen-Westat *(17)* in which relationships between relative bridge width and accident rate, injury rate, and accident property damage were developed using data from the studies by Gunnerson *(13)* and Fritts *(8)*. Accident reduction factors were developed from these relationships so that expected benefits from bridge widening could be estimated. There are severe problems associated with how the data were used in developing these relationships. Thus, the findings and conclusions of this study are highly questionable.

In another study Jorgensen *(18)* reported that wider lane and pavement widths on bridges resulted in lower accident rates, citing the studies by Jorgensen-Westat *(17)* and Gunnerson *(13)*, and that wider shoulders on bridges or greater lateral clearance reduced the accident rate on Interstate highways, citing the study by Cirillo *(14)*. The study also developed the logical relationships (i.e., nonestablished) that accident rate would decrease as lane width on a bridge increases with little difference between 11- and 12-ft lanes, and that accident rate would increase on multilane highways if the right shoulders would not accommodate a parked vehicle off the travel lanes.

McFarland et al. *(19)* used the relationships developed in the Colorado study *(15)* and the Jorgensen-Westat study *(17)* to estimate accident reduction factors and the effectiveness of widening a bridge. The relationships were accepted at face value with no critical review although the authors appropriately pointed out that the results were based on numerous assumptions and could be subjected to substantial error.

In a recent report on synthesis of safety-related research *(20)*, three studies were cited: Jorgensen-Westat *(17)*, McFarland et al. *(19)*, and Woods et al. [note that this study was part of the study by Ivey et al. *(6)*]. Again, the results of the cited studies were reported at face value in the synthesis with no critical review.

CONCLUSIONS AND DISCUSSION

The major conclusions that can be drawn from the studies reviewed are summarized next.

Bridge width should, at the very minimum, be as wide as the approach traveled way width; that is, there should be no lane width reduction on the bridge. Accident rates are shown to be significantly higher for bridges with width less than the approach traveled way width.

For bridges on two-lane highways, there is general agreement among several studies that the bridge width should desirably be at least 6 ft wider than the traveled way width; that is, 3-ft shoulders should be provided. There appears to be little change in accident rate or safety benefits gained when the bridge width is increased further. This conclusion is also supported by results from studies of driver behavior. The minimum desirable bridge width is therefore 26 ft for roadways with 10-ft lanes, 28 ft for 11-ft lanes, and 30 ft for 12-ft lanes. Bridges of similar width were found to have higher accident rates on roadways with no approach shoulders than those on roadways with approach shoulders. Also, for roadways with approach shoulders, accident rates are highest for bridges with greater than 50 percent shoulder reduction. Accident rates decrease significantly for bridges with 1 to 50 percent shoulder reduction. However, there is little difference in accident rates between bridges with 1 to 50 percent shoulder reduction and those with no shoulder reduction. This suggests that the shoulder width on a bridge should be at least one-half of that of the approach roadway.

In summary, the shoulder width on a two-lane bridge should desirably be at least 3 ft or one-half of the approach roadway shoulder width, whichever is greater. The desirable bridge width is simply twice the sum of lane plus shoulder widths.

Relationships between accident rate and the width or relative width of bridges on two-lane highways were developed in several studies. The best available relationship is judged to be the quadratic equation developed by Turner *(16)* as follows:

$$Y = 0.50 - 0.061\,(RW) + 0.0022\,(RW)^2$$

where Y is the number of accidents per million vehicles, and RW is the bridge relative width in feet.

Table 3 gives the expected accident rates for various relative bridge widths as calculated from this equation. It should be cautioned, however, that the accident rates were based on "bridge-related" accidents and may be subjected to substantial error. Thus, the accident rates should be viewed in relative terms and not as absolute measures. Using these expected accident rates, it is possible to estimate the potential percent increases in accident rate for bridge widths between the minimum (i.e., equal to the traveled way width) and the desirable minimum (i.e., shoulder width of 3 ft or one-half of the approach shoulder width), as given in Table 3.

TABLE 3 Expected Percent Increase in Accident Rate for Relative Bridge Widths Less than the Desirable Minimum

Relative Bridge Width (ft)	Expected No. of Accidents per Million Vehicles	Desirable Minimum Relative Bridge Width (ft)		
		6	8	10
0	0.50	139	239	381
1	0.44	111	199	323
2	0.38	84	161	270
3	0.33	60	127	221
4	0.29	38	95	177
5	0.24	18	67	137
6	0.21	0	42	101
7	0.17	–	19	69
8	0.15	–	0	42
9	0.12	–	–	18
10	0.10	–	–	0

NOTE: Dashes indicate not applicable.

For approach shoulder widths of 0 to 6, 8, and 10 ft, the desirable minimum relative widths are 6, 8, and 10 ft, respectively. The expected percent increase in accident rate is then calculated as

$$\text{Percent increase} = \frac{R(X) - R(DM)}{R(DM)} \times 100\% \tag{6}$$

where $R(X)$ is the expected accident rate for relative width X, and $R(DM)$ is the expected accident rate for desirable minimum relative width.

For two-lane twin structures, the extent of information available from the literature is more limited and is categorical in nature. Mak and Calcote *(2)* reported that accident rates decreased sharply when shoulder width was increased from greater than 50 percent shoulder reduction to between 1 and 50 percent. However, there was little difference in accident rates between bridges with 1 to 50 percent shoulder reduction and those with no shoulder reduction. Cirillo *(14)* reported that accident rates were lowered significantly when the shoulder width increased from less than 6 ft to between 6 and 9 ft and remained little changed for shoulder widths of beyond 9 ft. A study in Colorado *(15)* revealed that accident rates were much higher for bridges with 30-ft width (i.e., a total of 6 ft of shoulders) than those with 38-ft width carrying the full approach shoulders (i.e., 10-ft right shoulder and 4-ft left shoulder). A driver behavior study *(5)* indicated that vehicle lateral movement toward the centerline was minimal for a shoulder width of 6 ft.

The data suggest that the minimum shoulder width on a bridge should be the greater of 6 ft or one-half of the approach shoulder width. A minimum bridge width of 33 ft, consisting of two 12-ft lanes, a 3-ft left shoulder, and a 6-ft right shoulder, is therefore recommended for two-lane twin structures. There is insufficient information available from the literature to establish more detailed relationships between accident rate and bridge width or relative bridge width.

Bridge width appears to have some marginal effect on accident severity for two-lane twin structures, with higher severity for bridges with greater than 50 percent shoulder reduction, but does not appear to have any effect on accident severity for two-lane single structures.

In using the study findings presented in this paper, the following considerations should be borne in mind:

1. The relationships represent the best information available from the literature. However, it should be emphasized that these relationships are usually fairly weak and lacking in specificity, such as by ADT groups and highway type.

2. The relationships developed did not take into account factors other than bridge width and relative bridge width that may influence accident rates at bridge sites, such as structure length, type (e.g., deck versus truss), presence or absence of curb on the bridge, approach alignment, pavement surface condition, traffic mix, operating speed, and so forth. Unfortunately, there is insufficient information available from the literature to determine the effects of these factors on accident rates and their interactions with bridge width or relative bridge width. Nevertheless, these other factors should be taken into consideration when selecting the appropriate bridge width.

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