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Safety at Narrow Bridge Sites

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 20-7, Task 7, "Safety at Narrow Bridge Sites", by D. L. Ivey, R. M. Olson, N. E. Walton, G. D. Weaver, and D. L. Woods, Texas Transportation Institute, College Station, Texas

THE PROBLEM AND ITS SOLUTION

Many of the existing roads in the United States were built before the adoption of modern design standards. In consequent attempts to improve the capacity and safety of the older roads, pavement widening often has been used, although in many cases funds have not been available to widen the bridges. These "narrow" bridges stand as potential hazards to all users. This report describes methods--other than widening of the bridge--for reducing the hazards associated with narrow bridges. A major feature is the development of a bridge safety index (BSI) for determining priorities in dealing with problems involving bridges having restricted width. Time and funds did not permit evaluation of the BSI by comparison of predicted hazard levels with actual accident experience.* However, its development was based on information acquired during the study and the experience of the researchers. The BSI approach is presented in the form of tables and figures readily usable by practicing engineers. It is considered suitable for trial implementation as a tool for making a reasonable estimate of the relative degree of hazard at various restricted bridge sites. By use of an example problem, the BSI is defined explicitly enough to permit its direct application to practice.

FINDINGS

It is difficult to quantitatively define a "narrow" bridge in terms of actual bridge width because this implies that width is the only factor in the

* The Texas Transportation Institute is currently working on a trial implementation of the BSI concept for the Texas Department of Highways and Public Transportation.

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narrow bridge problem. Such factors as bridge width in relation to approach pavement width, sight distance, traffic volume, traffic speed, and distractions all influence safety at any given bridge site. In an attempt to define the narrow bridge problem, data on speed and lateral placement of vehicles at 25 bridge sites of various geometric characteristics were collected and analyzed by the Texas Transportation Institute. From these data it was determined that there was little lateral movement of vehicles when approaching bridges more than 24 ft in width (the clear width of pavement measured at right angles to the center of the roadway). On bridges 15 ft or less wide, movement toward the center of the roadway averaged 4 ft. The width at which most drivers place the left edge of their vehicle on the centerline when unapposed by traffic is 17 ft to 18 ft. Some of the observations from the data are as follows:

1. Any bridge less than 24 ft in width should be considered a restricted-width bridge, but not necessarily a hazardous bridge site.

2. Any bridge less than 18 ft in width should be considered a one-lane bridge.

3. Any bridge 15 ft or less in width should be considered a hazardous site.

Bridge Safety Index

On the basis of the data collected and the background and experience of the research agency, a rather simple bridge safety index (BSI) was developed as the sum of ten individual bridge site rating factors, as follows:

$$BSI = F_1 + F_2 + \ldots + F_{10} \tag{1}$$

With the exception of F_1, F_2, and F_3, which are rated from 0 to 20, ratings from 1 to 5 are assigned for each of the factors, as given in Table 1. The most ideal bridge site conditions would result in a BSI of 95 and extremely hazardous sites would have values less than 20. Because traffic speed influences the relative safety of a site, it was decided to modify the BSI by the ratio of the appropriate speed, V_a, for a given site and the 85th percentile traffic speed, V_{85}. Thus, the speed-modified value is

$$BSI' = (V_a/V_{85})\ BSI \tag{2}$$

The value for V_a is obtained from Figure 1 by entering with the unmodified BSI.

The BSI'-value can be used to provide an estimate of the relative degree of hazard of various restricted-width bridge sites. As a result, corrective action can be taken at the more hazardous sites even if extensive accident records are not available.

Example Problem

To illustrate the computation of the BSI' for a specific bridge, such as shown in Figure 2, the approach roadway width is assumed to be 24 ft, the bridge width 23 ft, and other geometrics similar to those shown in the figure. Average daily traffic is assumed as 2,500 and the 85th percentile speed as 50 mph. The F-values and bases for their selection are as follows:

Designation	Definition	Assumed Condition	Conversion Source	F-Value
F_1	Bridge width	23 ft	Figure 3	19
F_2	Bridge width/approach width	23/24 = 0.96	Table 1	10
F_3	Guardrail and bridge rail structure	Poor	Table 1	5
F_4	Approach sight distance	400 ft V_{85} = 50 mph	Table 1	2
F_5	Tangent distance to curve	300 ft Curvature = $4^{\circ}30'$ 100 + 300/4.5 = 89	Table 1	3
F_6	Grade continuity	2.5 (see Fig. 4)	Table 1	4
F_7	Shoulders	None paved, no reduction	Table 1	5
F_8	Traffic volume	2,500 vpd Capacity = 20,000 vpd 2,500/20,000 = 0.125	Table 1	4
F_9	Traffic mix	Normal	Table 1	3
F_{10}	Distractions	Moderate	Table 1	3
			BSI	= 58

From Figure 1, the appropriate speed, V_a, is determined as 33 mph. The 85th percentile speed, V_{85}, is 50 mph. Therefore, BSI' = 33/50 x 58 = 38 and the BSI'-value indicates that this bridge is a candidate for further evaluation and possible corrective action. A review of the F-values identifies F_3, bridge rail structure, as the factor that could be modified to increase the BSI. The substantial difference between the V_a- and V_{85}-values suggests that some signing and other measures to reduce traffic speed would also improve safety at the site.

Corrective Measures

The study identified a number of corrective measures that can be applied to hazardous bridge sites when widening is not considered economically feasible. The suggested corrective measures are approaches that can be considered, along with engineering judgment, to reduce the probability and severity of accidents at potentially hazardous sites. They are described briefly in the following. It should be recognized that such factors as traffic volume and the proportion of commercial vehicles will influence the selection of an appropriate measure.

Realign roadway - Where sight distance problems are apparent and traffic control measures appear to fail, realignment of the bridge approach roadways may be the only acceptable alternative.

Replace bridge rail - Existing bridge rails will often snag encroaching vehicles and increase the severity of accidents. Installation of a smooth rail increases the probability of redirecting the vehicle. Actual bridge width may also be increased, as indicated in Figure 5.

Change approach grades - Where grade continuity is a problem, consideration should be given to major changes in grades of the approaching roadway.

Install approach guardrail - Approach guardrail should be used at all restricted-width bridge locations, following the examples and standards in Highway Design and Operational Practice Related to Highway Safety, AASHTO, 1974.

Place edge lines and transition markers - Reflectorized edge lines can be used in the transition from a wide roadway approach to a restricted-width bridge. Diagonal shoulder markers, rumble strips, and raised reflectors can also be used effectively in the transition zone of higher-speed highways.

Install narrow-bridge and advisory speed signs - Where a bridge is 24 ft or less in width or where the bridge width is substantially less than the approach width, narrow-bridge and advisory speed signs should be considered in accordance with the Manual on Uniform Traffic Control Devices, U. S. Government Printing Office, 1970.

Install signs and remove centerline stripes on one-lane bridges - Where a bridge is less than 18 ft wide (20 ft where there is a high proportion of commercial vehicles), appropriate signs (such as one-lane, yield, stop, and advance warning) should be installed in accordance with the Manual on Uniform Traffic Control Devices, U.S.G.P.O., 1970. Any centerline stripes should be removed from the bridge and approaches and markings provided for the transition from two-lane to one-lane operation. Where extremely high risk is involved, positive control (such as traffic-actuated signalization) should be considered.

Re-route commercial vehicles - There may be situations where through commercial traffic should be re-routed around restricted or one-lane bridge sites.

Environmental control - Consideration should be given to the control or elimination of access, distracting lights, and other roadside disturbances (such as boat ramps and fishing docks) in the vicinity of restricted-width bridge sites.

Effectiveness of Corrective Measures

Data for a "before" and "after" type of evaluation of corrective measures at restricted width bridge sites were available from a Texas study. Accident data over a two-year period indicated that the fatal accident rate of a section of U S 90 near Gonzales, Texas, was 56 percent higher than the statewide average. Many of the reported accidents were located in the vicinity of bridges. A comprehensive safety program was conducted, involving extensive corrective measures at the bridges along the section. The bridges were 24 ft and 26 ft in width, with concrete rail and concrete post with steel rail. The roadway generally had a 24-ft paved surface width with 8-ft paved shoulders and thus was substantially wider than the bridge. The corrective measures included:

1. A 4-in. edgeline from a point 1,000 ft from the bridge on the outside edge of the shoulder, tapering to the roadway pavement edge approximately 225 ft from the bridge and extending across the bridge.

2. Two-foot wide diagonal shoulder markers at 45^{o}, placed at 20-ft centers.

3. Raised jiggle bars on every fourth diagonal shoulder marker.

4. Raised pavement markers just inside the edgeline on 40-ft centers.

5. Approach guardrail beginning about 225 ft in advance of the structure and at an offset of 8 ft, tapering to the bridge and continuing onto or across the bridge.

6. Post-mounted delineators placed behind the guardrail.

Figure 6 shows the general plan for corrective measures at a bridge approach. Table 2 contains the before and after accident experience at the bridges in the study section. The corrective measures appear to have been extremely effective in reducing the number of reported accidents.

APPLICATIONS

The development of the BSI is a significant accomplishment of this study. It is based on a limited amount of data plus the experience and opinions of the researchers and should be verified and/or modified by operating highway agencies. However, it has the advantage of being quite simple and uses readily available information. Because of the need for a realistic method of estimating the relative degree of hazard of various bridge sites where extensive accident records are not available, the BSI concept should be used on a trial basis to develop verification and modification information. The numerical values of the bridge evaluation factors may need to be revised with the collection and analysis of more information. However, when considering the criticality of the need for immediate corrective actions at restricted-width bridge sites to reduce accidents, it is apparent that use of any available tools with reasonable probability of success is imperative.

The recommended corrective measures are based primarily on engineering judgment and are consistent with corrective measures applied to a group of bridges along a section of highway in Texas. There was substantial reduction in the number and severity of reported accidents on the Texas study section after the improvements. This limited verification provides sufficient evaluation to indicate good probability of success when the recommended corrective measures are implemented.

TABLE 1

FACTORS USED TO DETERMINE SIMPLIFIED BRIDGE SAFETY INDEX

	BRIDGE EVALUATION FACTOR	FACTOR RATING FOR F_1, F_2, AND F_3				
		0	5	10	15	20
F_1	Clear bridge width (ft)	(See Figure 3)				
F_2	Bridge lane width (ft) / Approach lane width (ft)	≤0.8	0.9	1.0	1.1	≥1.2
F_3	Guardrail and Bridge rail structure	Critical	Poor	Average	Fair	Excellent
		FACTOR RATING FOR F_4 - F_{10}				
		1	2	3	4	5
F_4	Approach sight distance (ft) / 85% approach speed (mph)	≤5	7	9	11	≥14
F_5	100 + Tangent distance to curve (ft) / Curvature (degree)	≤10	60	100	200	≤300
F_6	Grade continuity (%)*	10	8	6	4	≤2
F_7	Shoulder reduction (%)	100	75	50	25	None
F_8	Volume/Capacity	0.50	0.40	0.30	0.10	0.05
F_9	Traffic mix	Wide discontinuities	Non-uniform	Normal	Fairly uniform	Uniform
F_{10}	Distractions and roadside activities	Continuous	Heavy	Moderate	Few	None

* Average grade + (Approach grade - exit grade).

TABLE 2

"BEFORE" AND "AFTER" ACCIDENT EXPERIENCE

Time Span	Time period (months)	ADT (vpd)	Accidents (No.), by Type: Hit Side of Bridge	Hit Bridge End	Hit Approach Bridge Rail	Total
(Before) Jan 69 - Oct 70	22	4780	10	7	3	20
(After) Nov 70 - Mar 72	17	5690	1	2	1	4

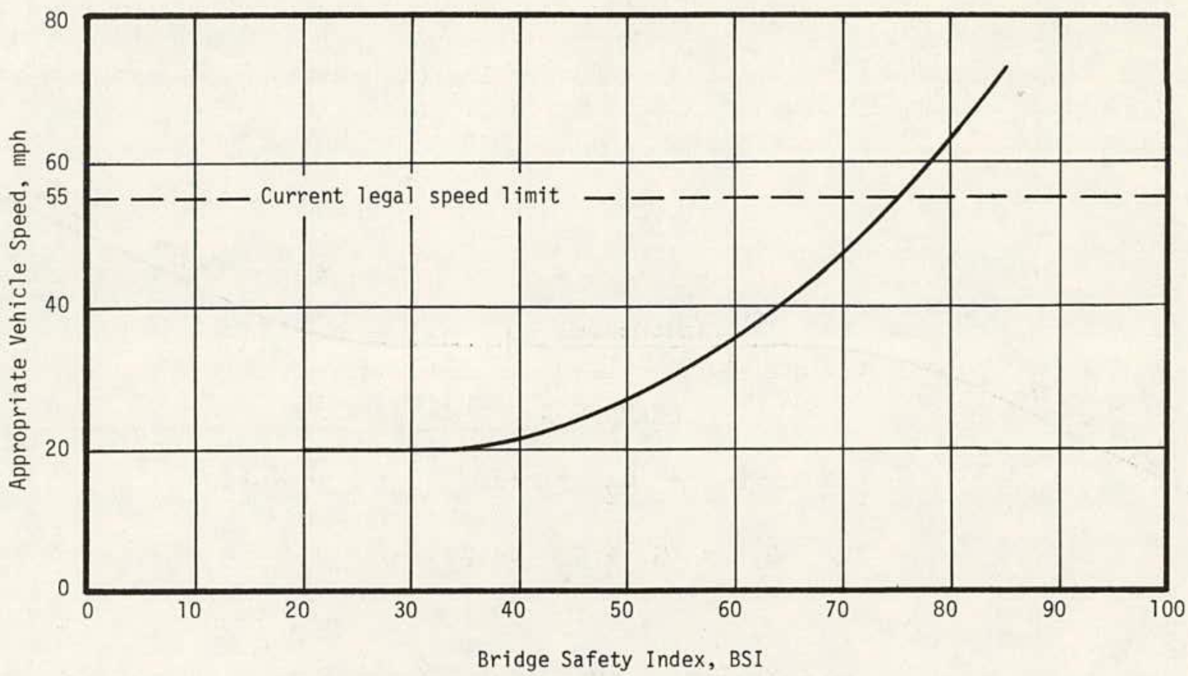


Figure 1. Appropriate vehicle speed vs BSI.

Figure 2. Restricted-width bridge site.

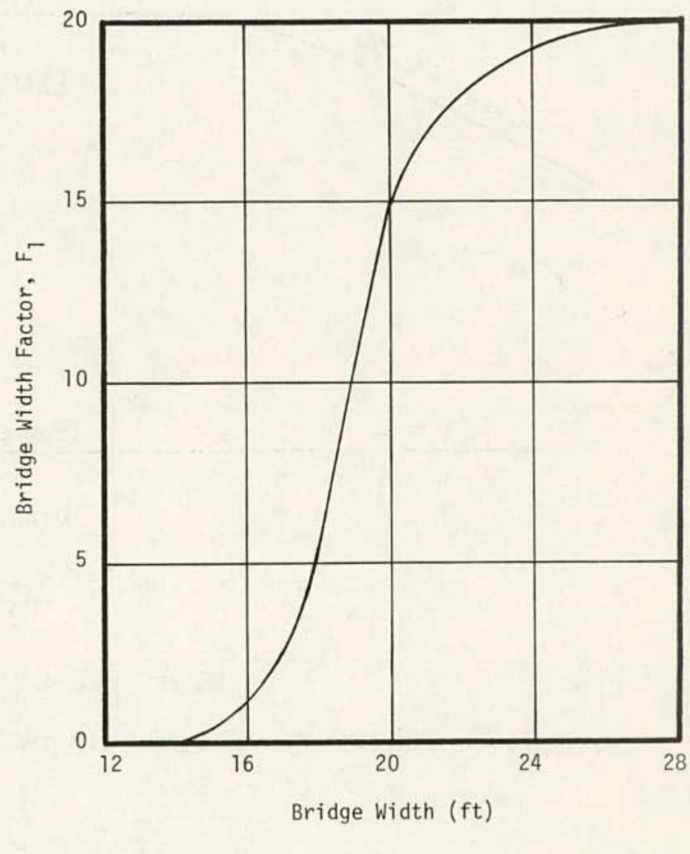
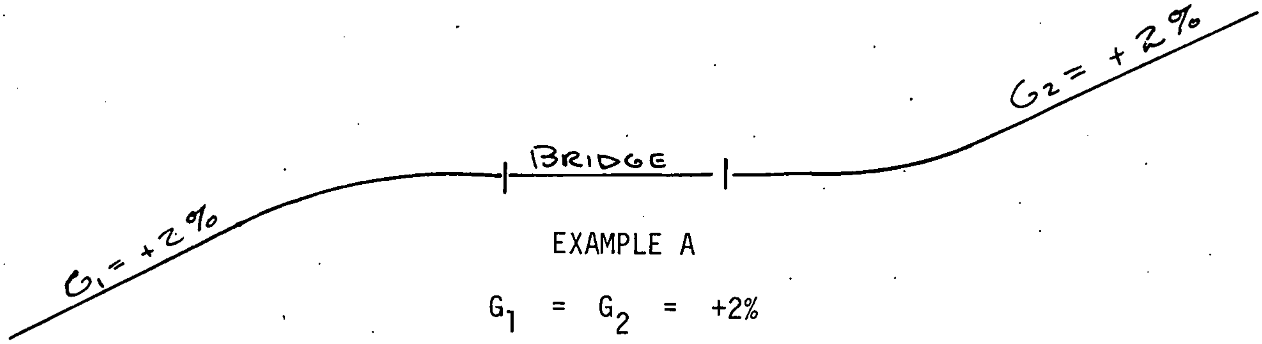


Figure 3. Weighting of bridge width factor.



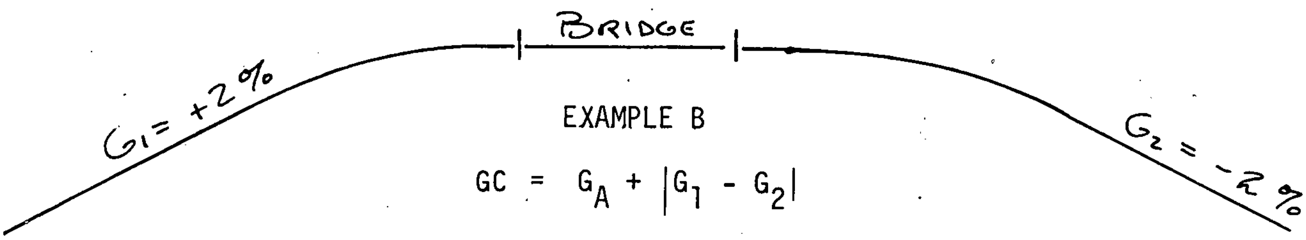
EXAMPLE A

$$G_1 = G_2 = +2\%$$

$$G_A = \frac{G_1 + G_2}{2} = 2\%$$

$$GC = G_A + |G_1 - G_2| = 2$$

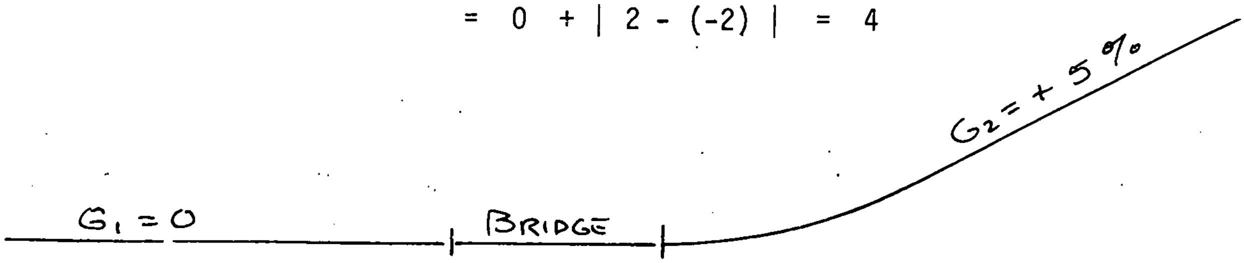
$|G_1 + G_2|$ is an absolute-value expression. It is the difference in grades, independent of sign.



EXAMPLE B

$$GC = G_A + |G_1 - G_2|$$

$$= 0 + |\ 2 - (-2)\ | = 4$$



EXAMPLE C

$$G_A = \frac{0 + 5}{2} = 2.5$$

$$GC = 2.5 + |\ 0 - 5\ | = 7.5$$

Figure 4. Examples of grade continuity factors.

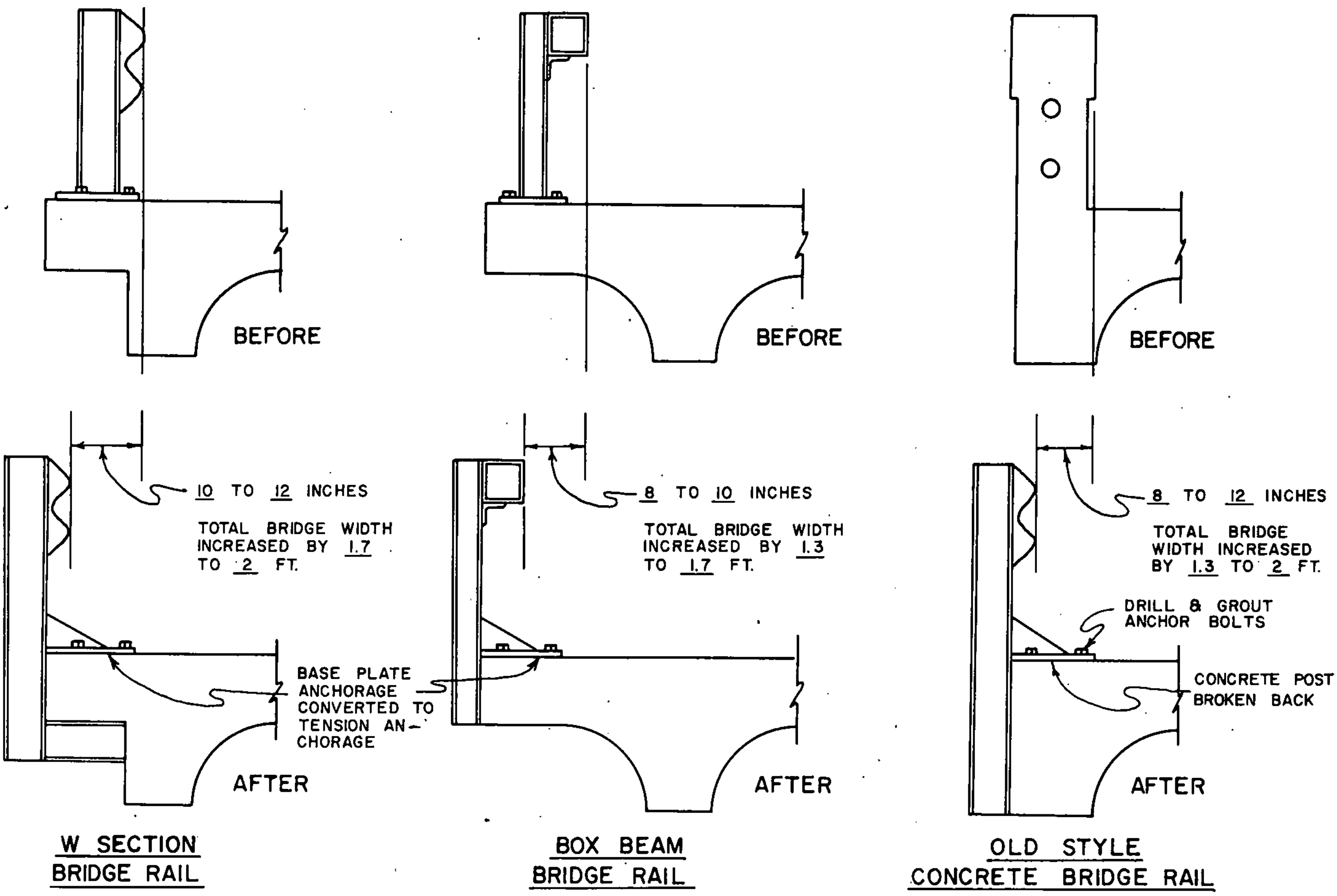


Figure 5. Examples of increasing effective bridge width by changing bridge rail structure without modifying basic structure.

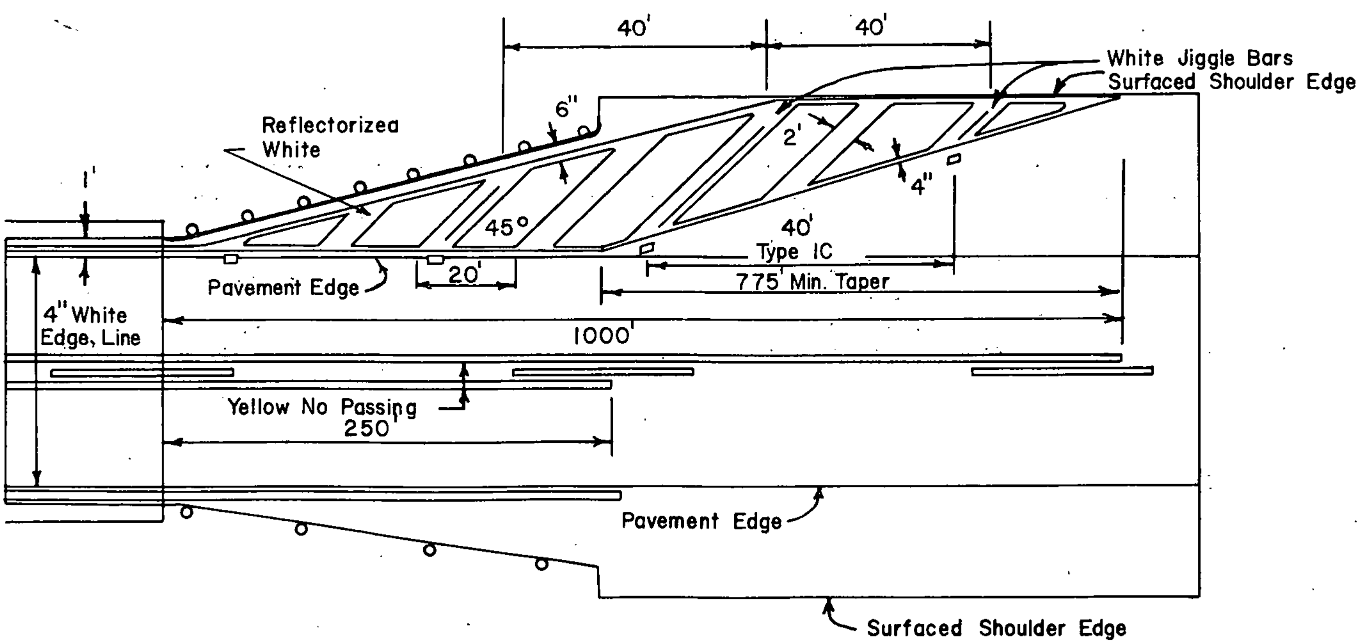


Figure 6. Typical approach treatment of restricted-width bridges.

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