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Guidelines for the Removal of Concrete Bridgerails on Narrow, Low-Volume Roads in Kansas

In the United States there are more than one million kilometers of low-volume roads, generally defined as having an average daily traffic (ADT) of less than 400 vehicles per day. In Kansas there are several thousand kilometers of these low-volume roads. Widths generally range from less than 3 meters to 7 meters. These roads cross thousands of bridges and culverts that were built many years ago before any thought was given to "forgiving roadsides," and they have massive concrete bridgerails and culvert headwalls which are roadside obstacles that can contribute to serious crashes when vehicles stray from the roadway. A study was conducted by Kansas State University (KSU) to analyze the crash risk to vehicles hitting these concrete structures. The researchers used the computer software program ROADSIDE to compare the probabilities and expected cost of crashes at bridge and culvert locations with bridgerails and headwalls vs. the expected cost of crashes with bridgerails and culvert headwalls removed. It was concluded that the expected costs of these crashes were less with the concrete rails and headwalls removed for ditch depths of 2.4 meters or less. A detailed discussion of the analysis and results are presented.

by Eugene R. Russell, Hani G. Melhem, and Rafael E. Morice

Kansas has thousands of low-volume rural roads (LVR), the majority being unpaved with gravel or earth surface, and thousands of small bridges and culverts. Most of these structures are old and narrow with old style, massive concrete bridgerails and culvert headwalls. The bridgerail shown in Figure 1 is typical of the Kansas concrete bridgerail (used at both culverts and small bridges) addressed in this paper. Other types of rail are rare on Kansas LVRs and are not addressed in this study. The term "culvert" includes a category of bridges with span lengths equal to or less than 6 meters, i.e., whether the typical structure addressed by this study is called a bridge or a culvert depends on the span length. These rigid, concrete structures (referred to as bridgerail(s) in this paper) can restrict pas-

sage by wide farm equipment, particularly combines. In many cases they can be more hazardous to an errant vehicle than the stream bed or ditch behind them. In most cases, they add nothing to the structural integrity of the structure and are a potential hazard to vehicles.

A Kansas State University (KSU) team conducted a study to investigate when it would be feasible and advantageous to remove concrete bridgerails. Guidelines for their removal were developed. Consideration had to be given to the structural integrity of the structure, safety of the motoring public, movement of farm equipment, and cost effectiveness. A statewide survey was conducted to determine the numbers of concrete bridgerail and concrete headwalls and the extent to which they cause problems.

Simply put, the main determinant in the decision to remove or not remove these old, concrete structures is whether vehicle damage is more severe when hitting the feature or when going into the ditch or stream unobstructed, as would be the case if the feature was removed. Figure 1 is a clear example of a location where intuitively one would believe that an errant vehicle would be subject to a more severe crash hitting the concrete bridgerail than going into the shallow ditch unobstructed, because the concrete bridgerail had been removed.

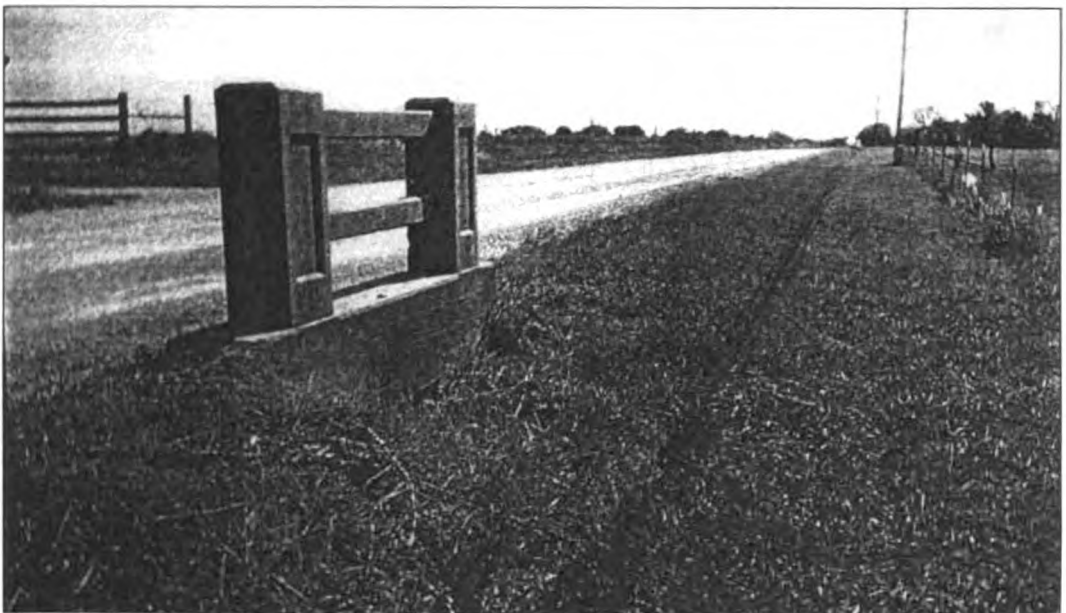
If there was a three or four meter drop-off into a deep ditch or stream, the choice would not be so clear. In some situations hitting a concrete rail could result in a less severe crash than going into a deep ditch or creek. The main objective of the study was to document the least severe of two scenarios: (1) hitting the concrete structure or (2) going directly into the ditch or stream. The main criterion would be ditch or stream depth, defined as the vertical distance from the edge

of the traveled way to the bottom of the ditch or stream.

It should be pointed out that other possible options, such as retrofitting outdated concrete rails with approved rail barrier, reconstructing ditches, etc., were not considered in the analysis. These and other options were considered beyond the scope of the contract for this study. The sponsor, the Kansas Department of Transportation (KDOT), was only interested in the bridgerail vs. no bridgerail options. However, further research in this area is recommended.

The main tool used by the team to develop guidelines was the computer program ROADSIDE, developed by the American Association of State Highway and Transportation Officials (AASHTO). This paper briefly discusses the computer program ROADSIDE and its normal use in guardrail decisions; presents the survey results documenting the extent of the Kansas problem with concrete bridgerails; explains how ROADSIDE was used to address the prob-

Figure 1: Example of Hazardous Concrete Bridgerail in Place at a Culvert on a Low Volume, Gravel Road



lem; and, finally, presents the KSU team’s recommendations and conclusions.

ROADSIDE

The computer program (ROADSIDE) was developed as a tool to provide input on decisions to improve roadside safety, particularly decisions related to the use of barrier rail (guardrail). ROADSIDE is widely used to assist designers in making informed choices regarding guardrail design and use. It follows the AASHTO *Roadside Design Guide* (AASHTO, 1996) cost-effective methodology.

The AASHTO guidelines recommend guardrails if the consequences of hitting a roadside object or running off the road would be more serious, in terms of cost, than those associated with striking the guardrail (AASHTO, 1996). ROADSIDE does two types of analysis: (1) roadside embankments (i.e., sloping roadside areas including ditch slopes), and (2) fixed objects. In both analyses, the program calculates the costs of vehicle crashes resulting from encroaching on the roadside (i.e., running off the road or hitting a roadside object). Crashes and crash costs are a function of average daily traffic (ADT), highway type, encroachment rate, vehicle speed, and corresponding encroachment angle. In the case of embankments, the crash costs are associated with speed, height of fill (depth of ditch), slope, and conditions of the slope. In the case of fixed objects, the crash costs are a function of the speed, the encroachment angle, the dimensions or “geometry” of the object, and the distance of the object from the edge of the roadway. In both cases, the equivalent annual costs of predicted crashes are calculated by ROADSIDE based on the input mentioned above plus a value for the costs associated with crashes of various severities. Values for crash costs currently used by KDOT are shown in Table 1.

Table 1: Total Average Crash Cost

Crash Type	Cost
Fatal	\$2,672,900
Major Personal Injury	185,050
Moderate Personal Injury	37,000
Minor Personal Injury	19,550
Property Damage Only	2,050

Source: KDOT (1997)

In the case of using ROADSIDE to decide whether to install a guardrail along a section of roadway, the cost for guardrail installation and maintenance, including repair after predicted crashes, is also input to the program. The annualized guardrail cost is compared to the annualized costs of predicted crashes. Where the projected annual cost of crashes exceeds the projected annual cost of the guardrail, the guardrail is warranted. The basis for using this criterion is the cost-effective methodology recommended by the *Roadside Design Guide* (AASHTO, 1996). Readers interested in the detailed results of ROADSIDE applied to guardrail on low-volume roads (LVR) are referred to the final report of a related study conducted at Kansas State University (Rys and Russell, 1997).

Input to ROADSIDE

To better understand the program ROADSIDE and the approach used for the concrete bridgerail and culvert headwall removal study, the input and program calculated variables are listed below as Items 2 through 15 with brief explanations where the meaning of the variable is not obvious. The user of ROADSIDE must input values for a number of variables specific to the area, roadway, and jurisdiction doing the study. In this study, values for several variables were decided by consensus of an advisory panel of KDOT engineers.

The ROADSIDE user is presented with a “screen” to input the data. Only brief explanations of “screen” items 2 through 15 are presented here. A detailed discussion of specific values used in this study is presented in a later section. Item 1 allows a project title to be entered.

- Item 2. *Traffic Volume*: The user supplies Average Daily Traffic (ADT).
- Item 3. *Roadway Type*: The user supplies road type. A two-way, two-lane road was used.
- Item 4. *Adjustment Factors*: The user can account for curvature and grade to adjust encroachments according to the user guide. The default value of 1.0 is generally used and was used in this study.
- Item 5. *Traffic Volume (ADT) and Encroachments*: The computer program ROADSIDE calculates encroachments from ADT and roadway type, or the user can input a value for encroachment rate or alternatively use the program default.
- Item 6. *Design Speed and Encroachment Angle*: The user defines speeds and encroachment angles, or ROADSIDE has default angles for various speeds. Default angles were used.
- Item 7. *Hazard Definition*: The computer program, ROADSIDE, defines hazard. In ROADSIDE a hazard (roadside object) is defined with a lateral offset (A) from the edge of the nearest driving lane, longitudinal length (L) parallel to the roadway, and width (W), generally perpendicular to the roadway. Values for A, L and W are input to the program.
- Item 8. *Collision Frequency*: The computer program ROADSIDE calculates collision frequency from previous input above (i.e., items 2 through 7).
- Item 9. *Severity Index*: The user inputs values for severity indices (SIs). Severity indices are estimates of the societal costs

- associated with an average projected crash with a given feature. ROADSIDE uses the SIs to determine cost of the crash. Five values of SIs, taken from the appropriate tables in the AASHTO, *Roadside Design Guide*, are needed to perform the analyses: one each for the force, the upstream side, the upstream corner, the downstream corner, and the downstream side of the feature. (For both embankment analysis and fixed objects analysis, the SIs used were taken from “A Cost-Effectiveness Selection Procedure,” a user’s guide and documentation for the computer program ROADSIDE, Appendix A.)
- Item 10. *Project Life and Discount Rate*: The user supplies values for project life and discount rate. Twenty years and 4% were used as directed by KDOT.
- Item 11. *Installation Cost*: The user supplies these values (KDOT supplied values) applicable to guardrail.
- Item 12. *Repair Cost/Crash*: The user supplies these values (KDOT supplied values).
- Item 13. *Maintenance Cost/Year*: The user supplies these values (KDOT supplied values).
- Item 14. *Salvage Value*: The user supplies these values (KDOT supplied values).
- Item 15. *Present Worth/Highway Department Costs*: ROADSIDE calculates the Total Present Worth (TPW) of projected crash costs and highway department costs incurred over a specific analysis period (the project life). Readers interested in the details of the calculations and theory on which they are based are referred to the *Roadside Design Guide* (AASHTO, 1996).

ROADSIDE also calculates annualized costs obtained by multiplying present worth values by a capital recovery factor (CRF).

Extent of Concrete Bridgerails and Concrete Headwalls in Kansas

To obtain knowledge of the number of concrete bridgerails and culvert headwalls in Kansas a statewide survey of counties was conducted. The major interest in conducting the survey was to obtain the following information (a three-year time period was used):

1. number of culverts in the county on county roads
2. number of culverts with concrete bridgerail or headwalls
3. number of requests for the removal of concrete bridgerails and culvert headwalls
4. number of bridgerails removed by county officials
5. reason for the removal
6. numbers of crashes, deaths or severe injuries involving concrete bridgerails and culvert headwalls

Forty-one of the 105 Kansas counties responded. Of the 41 counties responding to the survey, 27 counties (66%) indicated they have up to 200 locations each with concrete bridgerails with potential to restrict passage of wide vehicles and farm equipment. Two counties reported between 200 and 400, and six counties reported 400 or more. Six counties did not provide specific information on this item.

Respondents indicated that these concrete features create problems. Several counties indicated they received a large number of requests to remove certain bridgerails, and even though the counties did not take any action to remove them, they were eventually removed without the county's permission, presumably by farmers, or they were unintentionally hit and knocked down by large farm equipment. The main objection seems to be the width of farm equipment, i.e., equipment wider than the space between the concrete features. In recent years farm machinery has tended to increase in size.

With the increase in size of farm machinery, narrow roads with concrete bridgerails and culvert headwalls create restrictions to the free movement of farm equipment and are potential roadside hazards due to their close proximity to the roadway.

After the bridgerails were removed, 95% of the counties received no further requests and there was no change in the number of crashes after removal. Respondents in 41 counties reported that there were 23 crashes causing severe injuries created by culvert bridgerails.

Crash Data

With the help of the KDOT Bureau of Transportation Planning, a database containing specific motor vehicle crash information for all years from 1990 through 1996 was obtained. All crashes indicating a vehicle collided with a culvert were examined.

The fixed-object crash results obtained were examined in detail for 15 counties. The data from crashes into concrete bridgerails and culvert headwalls are summarized in Table 2.

Table 2: Crash Data Summary, Total Crashes in 15 Counties, 1990 through 1996

Category	Total %
Fatal Accidents	2
Severe Personal Injury	11
Moderate Personal Injury	31
Slight Personal Injury	19
Property Damage Only	37

Source: KDOT (1998)

After gathering all the crash data and surveys, visits were made to several counties. During these visits, the culverts that were reported to have had problems with bridgerails were inspected. The main objectives were to observe the condition of the concrete bridgerails or culvert headwalls and

to obtain general data needed for developing a cost-effective analysis for different culvert and small bridge locations. Data collected included the width of roadway at the approach and at the culvert, depth of ditch or stream (if any), i.e., the vertical distance between the edge of the roadway and the ditch bottom, and various dimensions including the concrete bridgerails and headwalls. Examples are shown in 18 color photographs contained in the full report (Melhem et al., 1998). These are similar to the figures shown in this paper.

Culverts and culvert headwalls were of several types and were difficult to categorize. Some of these concrete structures had been totally removed. Others were partially removed as shown in Figure 2. Others were massive concrete objects (such as shown in Figure 1) with no apparent purpose. Many were potentially dangerous concrete objects close to the sides of generally narrow, low-volume county roads.

Narrow bridgerails and culvert headwalls are potential roadside hazards and, where feasible, should be removed since it is likely that the rigid concrete rail can cause more serious damage to the motorist than a stream-bed or drainage area (Smith, 1983). The field observations discussed above are detailed in the final report of the study (Melhem et al., 1998).

Figure 2: Concrete Headwall Partially Removed



ROADSIDE Cost Effectiveness Analysis

The scope of this study was limited to the study of only two strategies:

1. remove the existing concrete structures at culverts/bridges and
2. do not remove the existing concrete structures at culverts/bridges (refer to Figure 1 for typical concrete structure)

ROADSIDE (Version 5.0) was used to compare the projected cost of two types of crashes at the same culvert location. The first is hitting a concrete structure and the other is going into the ditch as if the concrete structure had been removed. Details of how ROADSIDE was adapted for this study are presented below.

Variables Specific to the Study

ROADSIDE was developed mainly for high-volume roadways. However, there is no reason it should not be applicable to any roadway, provided that input values for the variables are valid for the roadway. This study dealt primarily with low-volume, two-lane, two-way county roads. Users should be cautioned that default values from ROADSIDE might not be applicable to low-volume roads. In this study all input values and default values used were deemed acceptable by consensus of the research team and the KDOT project monitor and advisory committee.

- **Average Daily Traffic**
This study deals with low-volume roads (LVR). Considering data obtained from several counties and from discussion with the county engineers, a mean value of 80 vehicles per day was assumed to be typical of the roads of concern in this study.
- **Highway Type**
Roadway widths of 4.9, 5.5, and 6.1 meters (16, 18, and 20 feet) were assumed

to characterize typical Kansas LVR road types of concern in this study. The input to the program treated the road as one lane at the culvert (or bridge), common for most of the problem locations, i.e., the road width used was the same as the lane width. This assumption for the analysis could increase expected crashes and crash cost; however, it would increase both types with or without concrete structure and should have little effect on the relative comparison.

- **Encroachment Rate**

Twice the default encroachment rate was used in the calculations because the ROADSIDE program and default rate was developed for higher class, state highways and it seemed logical that narrow, mostly gravel, low volume roads could have a significantly higher rate. Since the objective of the study was a comparison of two scenarios, i.e., the relative difference in crash costs, both determined with the same encroachment rate, the comparison should be insensitive to the encroachment rate.

- **Design Speeds and Encroachment Angles**
The encroachment angles in ROADSIDE depend on the speed of the traveling vehicle before the crash or collision. For the purpose of comparison, speeds of 50, 60, and 70 km/h (30, 35, and 45 mph) were considered in this study. These speeds have associated default encroachment angles of 13, 12.8, and 12.4 degrees, respectively. The default encroachment angles were used.

- **Project Life and Discount Rate**

The project life is usually taken as the expected service life of the structure. After conferring with the KDOT project monitor and advisory committee, the researchers were instructed to use a life of 20 years and a 4% discount rate. According to the *Roadside Design Guide*, this

value for discount rate is reasonable (AASHTO, 1996). The life for the concrete structures is indeterminate, but for relative, comparative purposes, 20 years was assumed to be adequate for the ROADSIDE analysis in this study. In any event, the concern is with the difference between two scenarios and the same project life and discount rate were used for both scenarios. Thus it is doubtful that other values of these parameters would significantly affect the results.

- **Culvert Location and Size**

A range of values was used for ditch depth to compute crash costs. These values ranged from 0.6 meters to 2.4 meters. This was done to establish a correlation between ditch depth and crash cost. Also, as a result of the county visits and examination of existing culverts, the following typical values were used in the ROADSIDE analysis.

Table 3: Assumptions for the Typical Culvert

Item	Value
Culvert Type	Box Culvert
Culvert Wing Type	45 (at each end section)
Ditch Width/Span	4.9 meters (16 feet)
Material	Reinforced Concrete

- **Concrete Bridgerail Location and Size**
In order to use ROADSIDE to compute the crash cost incurred by colliding with a concrete bridgerail similar to the one shown in Figure 1, a number of assumptions had to be made with regard to typical dimensions. Typical culvert values assumed for the study are shown in Table 3. After several field measurements, it was determined that the typical concrete bridgerail is a fixed object with a span length of 4.9 meters, a width of 0.3 meters, and a height of 0.6 meters. In the case of a vehicle hitting the concrete

bridgerail structure, the depth of the ditch was not a factor as it was for the case of the vehicle running off the road into the ditch. It was also assumed that there was no offset distance between the concrete rail and the edge of the roadway. Severity indices for hitting the typical concrete bridgerail described above were obtained from the *Roadside Design Guide*. These are as follows for the case of hitting the concrete bridgerail: (AASHTO, 1996, Table A.13.9, p. A-80).

Severity Index (SI) for:	50 km/h	60 km/h	70 km/h
Approach Side	3.4	3.8	4.2
Corner	3.4	3.8	4.2
Traffic Face	1.9	2.0	2.2

For the cases where the concrete bridgerails are removed or nonexistent, the depth of the ditch is the main factor affecting crash costs. Severity indices used in ROADSIDE for cases of no bridgerail were taken from the *Roadside Design Guide*. As stated in the footnote of that table, "*The ditch beyond the culvert end is also an obstacle and should be accounted for in an economic analysis.*" For example, the severity indices used for 0.6 meters depth are as follows for the case of going directly into the ditch or stream assuming no bridgerail: AASHTO, 1996, Table A.13.10, p. A-88.

Severity Index (SI) for:	50 km/h	60 km/h	70 km/h
Approach Side	2.6	2.8	3.0
Corner	3.0	3.3	3.5
Traffic Face	2.3	2.6	2.8

Indices for the other depths can also be found in AASHTO, 1996, Table A.13.10, p. A-88.

ROADSIDE Results

The ROADSIDE software was used in this study to compute crash costs for several combinations of vehicle speeds, culvert span length and ditch depths for each case: (1) assuming the concrete bridgerails had been removed, and (2) with the concrete bridgerails present. A comparative analysis was run for vehicle speeds of 50, 60 and 70 km/h and with ditch depth varied from 0.6 meters to 2.4 meters. Results are summarized below in Table 4 for a lane width of 4.9 meters. Similar analyses were performed for lane widths of 5.5 meters and 6.1 meters. In all cases, a zero offset value was used for the bridgerail.

For each combination of ditch depth and vehicle speed, the two cases are presented. Case 1, the case of a crash after the concrete bridgerail had been removed or was nonexistent (no concrete bridgerail), is basically the cost of crashing into the ditch. Case 2, the case of a crash with the concrete bridgerail, includes two conditions: (1) hitting the concrete bridgerail (collision), and (2) continuing into the ditch after hitting one of the concrete bridgerail ends. (In the case of a vehicle hitting the face of the bridgerail, it was assumed it would not go into the ditch.)

Case 2, condition 2 was considered because although a crash with the concrete bridgerail may prevent a vehicle from continuing into the ditch when hitting the face of the bridgerail while over the main span of a bridge or culvert, it was assumed the vehicle would continue into the ditch if it hit the approach or rear corners of the rail. Continuing into the ditch would increase damage (and crash costs) and the increase would be a function of ditch depth. Since ROADSIDE has no specific severity indices for this condition (case 2, condition 2) costs were obtained by running the program as for the case of no concrete bridgerail for different ditch depths and speed combinations but using severity indices appropriate for the

Table 4: Crash Cost for a 4.9 meters Lane Width; 50, 60 and 70 km/h Speed; and Ditch Depths of 0.6 to 2.4 meters

Ditch depth (meters)	Vehicle speed (km/h)					
	50 km/h		60 km/h		70 km/h	
	w/o rail	with rail*	w/o rail	with rail*	w/o rail	with rail*
0.6 meters	\$198	\$392	\$356	\$685	\$522	\$1,129
1.0 meters	\$289	\$454	\$471	\$768	\$781	\$1,327
1.2 meters	\$465	\$594	\$710	\$964	\$1,050	\$1,566
1.8 meters	\$774	\$822	\$1,102	\$1,285	\$1,556	\$1,998
2.4 meters	\$1,152	\$1,128	\$1,604	\$1,694	\$2,332	\$2,637

*These columns include costs of hitting the bridgerails (independent of ditch depth) which are \$235, \$395 and \$693 for vehicle speeds of 50, 60 and 70 km/h, respectively.

approach end and far corner of the concrete bridgerail. It was the consensus of the research team and KDOT project advisory committee that this approach would give acceptable results.

The cost of case 2 is therefore the sum of the cost of condition 1 hitting the bridgerail, and condition 2 damage from continuing into the ditch.

The above procedure was repeated for road widths of 5.5 m and 6.1 meters; the results are not presented here. (Tables and figures of all results can be found in the project final report, Melhem et al., 1998). Results were tabulated in a way similar to that of Table 3 for a 4.9 meters road width. For a speed of 50 km/h, crash costs for case 2 (concrete bridgerail present) were greater than those for case 1 for ditch depths less than 1.8 meters. At speeds of 60 and 70 km/h, costs for case 2 (concrete bridgerail present) were greater for ditch depths less than 2.4 meters.

The above considerations are most appropriate, safety-wise, for paved and good condition gravel LVR. The removal of bridgerails on lesser LVR (e.g., narrow, two-wheel-path type roads where speeds are expected to be less than 50 km/h), is not as important due to lower speeds and driver expectancy—the driver expects some hazards on these types of roads (KDOT, 1991).

Summary of Cost Analysis

When comparing the values obtained for leaving the concrete bridgerail in place and for removing the concrete bridgerail, one can see that the crash cost associated with a narrow bridge or culvert having a ditch depth less than or equal to 1.8 meters, will always be less with the concrete bridgerail removed. For ditch depths of up to 2.4 meters, 4 cases out of 9 gave higher costs with the concrete bridgerails removed, but the cost increase was only 5%. If one takes into account the inconvenience and cost to a farmer of having to move farm equipment by some other route, likely to be worth the 5% difference, this difference in costs becomes less significant. By interpolation and judgment, the team concluded that the “break point” should be a ditch depth of 2.1 meters, i.e., for ditch depths up to 2.1 meters (7 feet) crash costs are expected to be less when the concrete bridgerails are removed. If one believes that the cost to farmers is significant, then it would be more economical to remove concrete bridgerails from culverts and narrow bridges when the ditch depth is less than or equal to 2.4 meters (8 feet).

Conclusions Based on ROADSIDE

Based on this investigation, site visits, crash data analysis, professional expertise, and engineering judgment, the research team concluded that for the conditions and assumptions appropriate for Kansas LVR, ditch depths at bridges or culverts which are 2.4 meters (8 feet) or less in depth, the concrete bridgerail is probably the greater hazard. For depths greater than 2.4 meters (8 feet) the bridgerail end is probably a lesser hazard than crashing into the ditch unobstructed by a concrete bridgerail. It should be understood that in other areas of the world, area-specific input to ROADSIDE and/or different assumptions might lead to different values.

Recommendation

It is recommended that county highway agencies in Kansas remove concrete bridgerails from culverts and bridges having a ditch depth of 2.4 meters (8 feet) or less. For all other ditch depths judgment should be used when determining whether to remove the bridgerails.

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Removing Bridgerails; General Guidelines

Bridgerail removal depends on whether the bridgerail is a structural or nonstructural element of the bridge or culvert. Structural bridgerails are those designed to carry, distribute, or transfer part of the loads on the structure. To determine if a bridgerail is structural, one or more of the following can be done:

1. Check the road or bridge plans for the structure in question, if available,
2. Ask engineers in the Bureau of Local Projects of KDOT who can generally provide assistance in this matter,
3. Check with other county engineers, or
4. Seek services of a consulting engineer.

The most important aspect of bridgerail removal is how deep to cut the concrete bridgerail. For purposes of safety, concrete bridgerails should be removed flush with the roadway surface, but in no case should they extend higher than 100 mm (4 inches) above the roadway surface. Remains of concrete bridgerails extending more than 100 mm (4 inches) above the roadway are hazardous to vehicles and violate AASHTO guidelines. Typical roadway signing procedures discussed in the *Low Volume Rural Roads Handbook* (KDOT, 1991) should be followed.

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