USE OF GUARDRAIL ON LOW-VOLUME ROADS ACCORDING TO SAFETY AND COST EFFECTIVENESS

by

Margaret J. Rys
Associate Professor of
Industrial and Manufacturing Systems Engineering

and

Eugene R. Russell
Professor of Civil Engineering

Kansas State University
Manhattan, KS 66506

Prepared for

Kansas Department of Transportation
K-TRAN Project Number KSU-96-6

Vernon Everhart, P.E.
KDOT Monitor

Final Report

May 1997

1. **Report No.** K-TRAN: KSU-96-6	2. **Government Accession No.**	3. **Recipient Catalog No.**
4 **Title and Subtitle** USE OF GUARDRAILS ON LOW-VOLUME ROADS ACCORDING TO SAFETY AND COST EFFECTIVENESS		5 **Report Date** May 1997 6 **Performing Organization Code**
7. **Author(s)** Margaret J. Rys, Eugene R. Russell		8 **Performing Organization Report No.**
9 **Performing Organization Name and Address** Kansas State University, Department of Civil Engineering, Manhattan, Kansas 66506		10 **Work Unit No. (TRAIS)** 11 **Contract or Grant No.** C-887
12 **Sponsoring Agency Name and Address** Kansas Department of Transportation, Docking State Office Bldg., Topeka, Kansas 66612		13 **Type of Report and Period Covered** Final Report July 1995 to June 1999 14 **Sponsoring Agency Code** 106-RE-0079-01
15 **Supplementary Notes**		

16 Abstract

The objective of this study was to develop guidelines for the use of guardrail on low-volume roads (LVR) in Kansas according to safety and cost effectiveness. LVR are generally defined as roads with ≤400 average daily traffic (ADT), although many LVR's have much lower ADT's. It should be noted that the term "guardrail" means some sort of restraining device to keep errant vehicles that leave the roadway from crashing into a more dangerous roadside environment. Roadside is defined as the area beyond the traveled way and the shoulder (if any) of the roadway itself. Most experts prefer the term roadside barrier or "barrier rail." Others (as is the case with KDOT personnel) prefer the term "guard-fence" as being more general. Most local road personnel use the term guardrail. In this report the term guardrail will be used.

A comprehensive review of the research literature was conducted to explore and gather information on the use of guardrail on LVR according to safety and cost effectiveness. The purpose of this information search was to identify the general elements used to determine the need for guardrail on LVR and to review any specific guidelines already in use by other states. The principle findings from this literature review are presented in this report.

The computer program ROADSIDE is widely used to assist designers in making informed choices regarding alternate guardrail design concepts. ROADSIDE follows the Roadside Design Guide cost-effective methodology. The ROADSIDE program was adapted to Kansas LVR parameters. The ROADSIDE program was used to develop guidelines to determine whether guardrail is needed on fill embankments and for shielding roadside obstacles on secondary roads. The results are presented in this report.

It is recommended that KDOT consider endorsing the guidelines developed in the report to assist counties in evaluating the need for guardrail on their LVR.

17 **Key Words** Roadside Safety, Guardrail Guidelines, Low-Volume Roads, Cost Effectiveness, ROADSIDE Program.		18 **Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19 **Security Classification (of this report)** Unclassified	20 **Security Classification (of this page)** Unclassified	21 **No. of pages** 148	22 **Price**

Form DOT F 1700.7 (8-72) r:\ktran\17KSU97.7doc

PREFACE

This research project was funded by the Kansas Department of Transportation K-TRAN research program. The Kansas Transportation Research and New-Developments (K-TRAN) Research Program is an ongoing, cooperative and comprehensive research program addressing transportation needs of the State of Kansas utilizing academic and research resources from the Kansas Department of Transportation, Kansas State University and the University of Kansas. The projects included in the research program are jointly developed by transportation professionals in KDOT and the universities.

NOTICE

The authors and the State of Kansas do not endorse products or manufacturers. Trade and manufacturers names appear herein solely because they are considered essential to the object of this report.

This information is available in alternative accessible formats. To obtain an alternative format, contact the Kansas Department of Transportation, Office of Public Information, 7th Floor, Docking State Office Building, Topeka, Kansas, 66612-1568 or phone (785)296-3585 (Voice) (TDD).

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or the policies of the State of Kansas. This report does not constitute a standard, specification or regulation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The objective of this study was to develop guidelines for the use of guardrail on low-volume roads (LVR) in Kansas according to safety and cost effectiveness. LVR are generally defined as roads with ≤400 average daily traffic (ADT), although many LVR's have much lower ADT's. It should be noted that the term "guardrail" means some sort of restraining device to keep errant vehicles that leave the roadway from crashing into a more dangerous roadside environment. Roadside is defined as the area beyond the traveled way and the shoulder (if any) of the roadway itself. Most experts prefer the term roadside barrier or "barrier rail." Others (as is the case with KDOT personnel) prefer the term "guard-fence" as being more general. Most local road personnel use the term guardrail. In this report the term guardrail will be used.

A comprehensive review of the research literature was conducted to explore and gather information on the use of guardrail on LVR according to safety and cost effectiveness. The purpose of this information search was to identify the general elements used to determine the need for guardrail on LVR and to review any specific guidelines already in use by other states. The principle findings from this literature review are presented in this report.

The computer program ROADSIDE is widely used to assist designers in making informed choices regarding alternate guardrail design concepts. ROADSIDE follows the Roadside Design Guide cost-effective methodology. The ROADSIDE program was adapted to Kansas LVR parameters. The ROADSIDE program was used to develop guidelines to determine whether guardrail is needed on fill embankments and for shielding roadside obstacles on secondary roads. The results are presented in this report.

It is recommended that KDOT consider endorsing the guidelines developed in the report to assist counties in evaluating the need for guardrail on their LVR.

KEYWORDS: Roadside Safety, Guardrail Guidelines, Low-Volume Roads, Cost Effectiveness, ROADSIDE Program.

ACKNOWLEDGMENTS

The authors wish to thank the following individuals for their contributions to this study:

- Vern Everhart (Asst. Bureau Chief, Bureau of Local Projects, KDOT)
- Ron Seitz (Road Squad Leader, Bureau of Design, KDOT)
- Jerry Priem (Field Engineer, Bureau of Local Projects, KDOT)
- Norm Bowers (Johnson County Engineer)
- Dean Chesnut (Jewell-Republic County Engineer)
- Richard Teaford (Jefferson County Engineer)
- Gelene Savage (Staff Attorney, Office of Chief Counsel, KDOT)

SUMMARY

Study Overview

The Kansas Department of Transportation (KDOT), at the request of Johnson County, contracted with Kansas State University (KSU) through a K-TRAN project to develop guidelines for using guardrail on LVR in Kansas based on a cost-effectiveness analysis. A Technical Advisory Committee consisting of representatives from KDOT and counties was formed to provide expertise. The committee was primarily interested in guidelines for three types of roadside obstacles: 1) reinforced concrete box (RCB) culvert - straight wings (Figure S-1); 2) reinforced concrete box (RCB) culvert - flared wings (Figure S-2); and 3) reinforced concrete pipe (RCP) culvert - pipe/headwall (Figure S-3). Conditions considered were offset distance, Average Daily Traffic (ADT), speed and culvert end height. Guidelines were also requested for two types of roadside (considering the condition of the foreslope), ADT, speed and height of fill. The summary of parameters used in the analysis (Table S-1) and results are presented below. In this report removal or relocation of the hazard was not considered.

ROADSIDE program, Version 5.0, was used in the cost-effectiveness analysis to compare the cost of installing guardrail with the cost of doing nothing. The cost of the guardrail included the initial cost, repair cost, maintenance cost, and the cost of collisions with the guardrail. The do-nothing cost included the cost of collisions with a fixed object or a fill embankment. The guardrail was recommended if its costs were less than the do-nothing costs.

Threshold, or recommended values, was defined as points at which the cost of the guardrail equaled the cost of doing nothing. Certain parameters were varied in ROADSIDE.

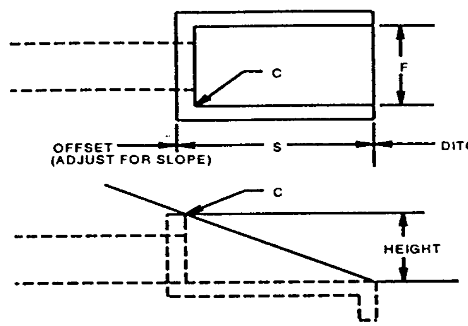
For the accident cost on embankments, the design speed, slope, height of fill, and traffic volume were varied and a guardrail was recommended when the accident costs of running down the embankment was equal or greater than the guardrail cost. From the break-even point, an increase in ADT, height of fill, or steepness of slope resulted in the do-nothing alternative being more expensive than the installation of guardrail (including associated accident costs).

In the case of fixed objects along the roadside, the design speed, the lateral distance of the object from the edge of the roadway, and traffic volume were varied. A guardrail became economically justifiable when the accident costs of colliding with the fixed object equaled or exceeded the guardrail cost. From the break-even point, increasing the ADT or locating the object closer to the roadway resulted in the do-nothing alternative being more expensive than the installation of guardrail (including associated accident costs).

Results

Results are from a cost-effectiveness analysis based on several assumptions, which are either input into the ROADSIDE program or inherent within the program; therefore, the results should be used with judgement after considering other non-economic factors.

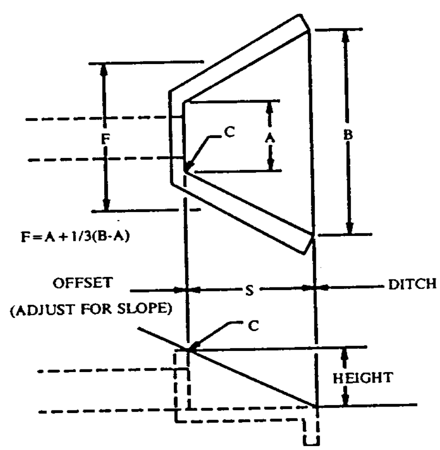
Culvert Ends:
Culvert Axis Transverse to traffic
Culvert End Type D
(See sketch below.)



S = Approach Side, C = Corner, F = Traffic Face

Figure S-1. RCB Culvert - Straight Wings (*Roadside Design Guide*, 1996, p. A-87)

Culvert Ends:
Culvert Axis Transverse to traffic
Culvert End Type E
(See sketch below.)



S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

Figure S - 2. RCB Culvert - Flared Wings (*Roadside Design Guide*, 1996, p. A-88)

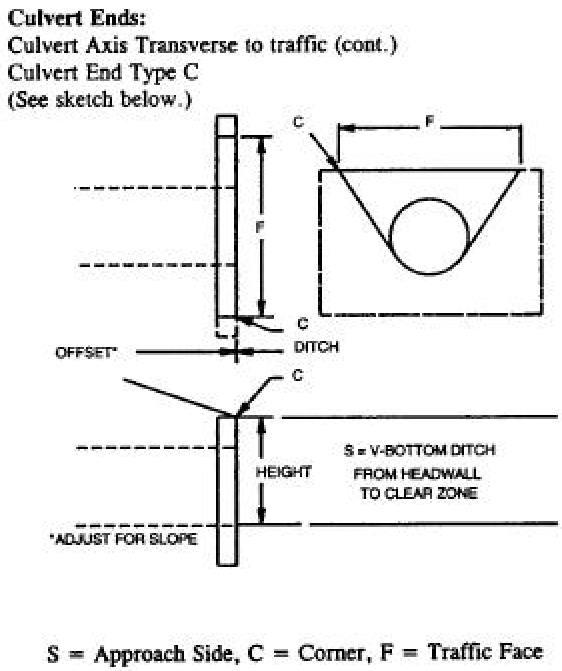


Figure S - 3. RCP - Pipe/Headwall (Roadside Design Guide, 1996, p. A-86)

Roadside Obstacle

RCB Culvert - Straight Wings. Based on the total life cycle cost analysis, the guardrail was economically justifiable for speeds of 90 km/h, ADTs of 300 or higher and culvert end height of 2.4 meters. For details see Table S-2 and Appendix A. The results indicated that the guardrail was not economically justified if the culvert's lateral offset from the nearest driving lane was two or more meters.

RCB Culvert - Flared Wings. The study results indicated that, under all conditions, thee guardrail was not economically justified if the culvert's lateral offset from the edge of the nearest driving lane was more than three meters. For some other conditions, installation of guardrail was economically justifiable. Details are presented in Table S-3 and Appendix A.

RCP Culvert - Pipe/Headwall. The study results indicated that the guardrail was not economically justified if the average daily traffic was less than 100. Guardrail was economically justifiable for some other conditions. Details are presented in Table S-4 and Appendix A.

Utility Poles. Based on the total life cycle cost analysis, the guardrail was economically justifiable for speeds of 90 km/h, ADTs of 400 and lateral offset of 0.0 m and 0.3 m. Details are presented in Table S - 5 and Appendix B.

Embankments. (Definitions of surface conditions B and C are presented in Table S-6.) The study results concerning guardrail installation on roadside embankments indicated that the guardrail was not economically justified for either 1:4 or 1:3 foreslopes with slope surface condition B, regardless of the design speed and ADT. For 1:3 foreslopes with slope surface condition C, ADT of 400, speed of 90 km/h and height of fill of four or more meters installation of the guardrail was economically justifiable. Guardrail was economically justifiable on most 1:2 foreslopes with surface condition B and C. Details are presented in Table S-6 and Appendix C.

Conclusions

Application of the ROADSIDE microcomputer program produced valuable results that should provide for a more cost-effective use of guardrail on rural, low-volume roads in Kansas. It is important to note that the procedures and input parameters used in this study were based on the latest information available at the time. Also, considerations beyond cost-effectiveness may be important.

Recommendations

The guidelines for guardrail developed in this study should be used by counties when considering the need for guardrail at specific locations on their rural, low-volume roads.

1. Tables S-2, S-3, S-4, and S-5 and Appendix A and B should be consulted for roadside obstacles when evaluating a need for guardrail.

2. Specifically, Table S-6 and Appendix C should be consulted for guardrail on a fill embankment.

Table S-1. Summary of Parameters Used for the Kansas Study, Cost-Effectiveness Analysis Using "ROADSIDE".

Costs by Severity Level	Encroachment Rate	Enc. Angle and Traffic Vol. Cap	Swath Width
Based on FHWA's Tech. Adv. Dated October 31, 1994. Costs are also based on the change of the Consumer Price Index from January 1994 (146.2) to January 1995 (150.3). Fatality $2,672,900 Severe Injury $ 185,000 Moderate Injury $ 37,000 Slight Injury $ 19,550 PDO Level 2 $ 2,050 PDO Level 1 $ 650	Based on encroachment model suggested by Stephens (1992) for low ADT ranges (ADT < 3,000). The encroachment rate was originally recommended in the AASHTO's 1977 *Guide for Selecting, Locating and Designing Traffic Barriers.* Enc. Rate = 0.001035424 * (ADT) enc/km/yr or Enc. Rate = 0.00166 * (ADT) enc/mi/yr	ROADSIDE default values: Encroachment angle at 50 km/h (30 mph) = 13 Encroachment angle at 60 km/h (35 mph) = 12.8 Encroachment angle at 70 km/h (45 mph) = 12.4 Encroachment angle at 80 km/h (50 mph) = 12.0 Encroachment angle at 90 km/h (55 mph) = 11.6 Traffic Volume Cap per lane = 10,000/day	ROADSIDE Default Value: 3.6 m (12 ft)

Parameter	Feature Location/Size	Severity Indices	Project Life/Disc. Rate	Installation/Salvage/Repair/Maintenance Costs
Values	<u>For embankment analysis</u>: *Length:* 60 m (200 ft.) for both (guard and embankment) 6 m (20 ft.) on culverts *Width of guardrail:* 0.3 m (1 ft.) *Width of embankment:* variable depending on embankment height and cross slope. *Foreslopes:* 1:2, 1:3, 1:4 *Height:* 0 to 10 m (0 to 32.8 ft.) *Lateral offset for guardrail:* 0.0, 0.3, 1, 2, 3, 5 m *Lateral offset for embankment:* 3 m (10 ft) <u>For the fixed objects analysis</u>: *Length*: 0.3 m (1 ft.) *Width*: 0.3 m (1 ft.) *Lateral offset of the fixed objects:* 0, 0.3, 1, 2, 3, 5 m	For both, embankment analysis and fixed objects analysis. The Severity Indices used were taken from the Appendix A: *A Cost-Effectiveness Selection Procedure; a user's guide and documentation for the computer program ROADSIDE.*	Project life: 20 yrs. Discount rate: 4%	Guardrail System considered: G4 (2w) - 6" x 8" Wood G4 (1s) - W6 x 8.5 Steel Installation Cost: $82.5/lin m ($25.00/lin ft.) End treatment: $0.00 Repair Cost: $500/accident Maintenance Cost: $3.00/lin/m ($1.00/lin ft.) Salvage Value: $0.00

Parameter	Traffic Volume/Growth Rate	Highway Type/Lane Width	Curvature/Grade	User Encroachment	Design Speed
Values	Volume: 100 vpd, 200 vpd, 300 vpd, 400 vpd Growth Rate: 1%	Two-lane, two-way Undivided roadway. Lane Width: 3 m (10 ft)	No adjustment factors were used (value of 1 for all three)	No factors were used	50, 60, 70, 80, and 90 km/h or 30, 35, 45, 50, and 55 mph

Codes: ft = feet; m = meters; mi = mile; km = kilometers; vpd = vehicles per day; enc = encroachments; yr = year; PDO = Property Damage Only; ADT = Average Daily Traffic; mph = miles per hour; km/h = kilometers per hour

Note: 0.3048 m = 1 ft 1.609 km = 1 mi 1.609 km/h = 1 mph

Table S-2. Guidelines for Guardrail on LVR; RCB CULVERT--Straight Wings

OFFSET (in meters)	ADT	400	300	200	100
	Speed (km/h)	Breakeven Culvert End Height			
0.0	50 60 70 80 90	NR NR NR NR **2.4 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR	NR NR NR NR NR
0.3	50 60 70 80 90	NR NR NR NR **2.4 m**	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
1.0	50 60 70 80 90	NR NR NR NR **2.4 m**	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
2.0	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
3.0	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
5.0	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR

m - meters
NR - Guardrail not recommended based on cost-effectiveness analysis
OFFSET - a lateral distance from the edge of the roadway to the culvert (See Figure S-1)

Table S-3. Guidelines for Guardrail on LVR; RCB CULVERT--Flared Wings

OFFSET (in meters)	ADT	400	300	200	100
	Speed (km/h)	Breakeven Culvert End Height			
0.0	50	NR	NR	NR	NR
	60	**2.4 m**	**2.4 m**	NR	NR
	70	**1.8 m**	**2.4 m**	NR	NR
	80	**1.8 m**	**2.4 m**	**2.4 m**	NR
	90	**1.8 m**	**1.8 m**	**2.4 m**	NR
0.3	50	NR	NR	NR	NR
	60	**2.4 m**	NR	NR	NR
	70	**2.4 m**	**2.4 m**	NR	NR
	80	**1.8 m**	**2.4 m**	NR	NR
	90	**1.8 m**	**1.8 m**	**2.4 m**	NR
1.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	**2.4 m**	NR	NR	NR
	80	**2.4 m**	**2.4 m**	NR	NR
	90	**1.8 m**	**2.4 m**	**2.4 m**	NR
2.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	**2.4 m**	NR	NR	NR
	80	**2.4 m**	**2.4 m**	NR	NR
	90	**1.8 m**	**2.4 m**	NR	NR
3.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	**2.4 m**	NR	NR	NR
	90	**2.4 m**	**2.4 m**	NR	NR
5.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR

m - meters
NR - Guardrail not recommended based on cost-effectiveness analysis
OFFSET - a lateral distance from the edge of the roadway to the culvert (See Figure S-2)

Table S-4. Guidelines for Guardrail on LVR; RCP CULVERT--Pipe/Headwall

OFFSET (in meters)	ADT	400	300	200	100
	Speed (km/h)	Breakeven Culvert End Height			
0.0	50 60 70 80 90	**2.4 m** **1.8 m** **1.8 m** **1.0 m** **1.0 m**	**2.4 m** **2.4 m** **1.8 m** **1.8 m** **1.2 m**	NR **2.4 m** **2.4 m** **1.8 m** **1.8 m**	NR NR NR NR NR
0.3	50 60 70 80 90	**2.4 m** **1.8 m** **1.8 m** **1.2 m** **1.0 m**	NR **2.4 m** **1.8 m** **1.8 m** **1.2 m**	NR NR **2.4 m** **1.8 m** **1.8 m**	NR NR NR NR NR
1.0	50 60 70 80 90	NR **2.4 m** **2.4 m** **1.8 m** **1.2 m**	NR **2.4 m** **2.4 m** **1.8 m** **1.2 m**	NR NR NR **2.4 m** **1.8 m**	NR NR NR NR NR
2.0	50 60 70 80 90	NR **2.4 m** **2.4 m** **1.8 m** **1.2 m**	NR NR **2.4 m** **1.8 m** **1.8 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR
3.0	50 60 70 80 90	NR NR **2.4 m** **1.8 m** **1.8 m**	NR NR NR **2.4 m** **1.8 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR
5.0	50 60 70 80 90	NR NR NR **2.4 m** **1.8 m**	NR NR NR NR **2.4 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR

m - meters
NR - Guardrail not recommended based on cost-effectiveness analysis
OFFSET - a lateral distance from the edge of the roadway to the culvert (See Figure S-3)

Table S - 5. Guidelines for Guardrail on LVR; UTILITY POLES

OFFSET (in meters)	ADT	400	300	200	100
	Speed (km/h)	Breakeven Cost			
0.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	**R**	NR	NR	NR
0.3	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	**R**	NR	NR	NR
1.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
2.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
3.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
5.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR

NR - Guardrail not recommended based on cost-effectiveness analysis
R - Guardrail is recommended based on cost-effectiveness analysis
OFFSET - a lateral distance from the edge of the roadway to the utility pole

Table S-6. Guidelines for Guardrail; SLOPES--Foreslope 1 to 2, 1 to 3 and 1 to 4

SLOPES	ADT	400	300	200	100
	Speed (km/h)	Breakeven Height of Fill			
Foreslope 1 to 2 Slope Condition B	50	NR	NR	NR	NR
	60	**8.0 m**	**10.0 m**	NR	NR
	70	**6.0 m**	**8.0 m**	**10.0 m**	NR
	80	**2.0 m**	**4.0 m**	**4.0 m**	NR
	90	**2.0 m**	**2.0 m**	**4.0 m**	NR
Foreslope 1 to 3 Slope Condition B	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
Foreslope 1 to 4 Slope Condition B	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
Foreslope 1 to 2 Slope Condition C	50	**10.0 m**	NR	NR	NR
	60	**8.0 m**	**8.0 m**	NR	NR
	70	**2.0 m**	**6.0 m**	**6.0 m**	NR
	80	**2.0 m**	**2.0 m**	**2.0 m**	**10.0 m**
	90	**2.0 m**	**2.0 m**	**2.0 m**	**4.0 m**
Foreslope 1 to 3 Slope Condition C	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	**4.0 m**	NR	NR	NR
Foreslope 1 to 4 Slope Condition C	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR

Slope surface Condition

B: Smooth but subject to deep rutting by errant vehicles half of the year.

C: Shallow gullies (100 to 200 mm deep), scattered small boulders (under 225 mm projections), scattered small trees (diameters 75 to 100 mm), or structurally substantial woody brush. Features spaced so that nearly all encroaching vehicles will encounter them.

m - meters

NR - Guardrail not recommended based on cost-effectiveness analysis

1. INTRODUCTION

Background

A 1983 study estimated that there are approximately 3.1 million miles of two-lane highways in the United States, which represent 97 percent of the rural mileage and 80 percent of the total U.S. highway mileage. Further, much of this mileage has relatively low traffic volumes. For example, of the 3.1 million miles of two-lane rural roads, approximately 90 percent (2.79 million miles) have an average daily traffic (ADT) of less than 1,000 vehicles per day (vpd). About 80 percent have an ADT of less than 400 vpd, and 38 percent carry less than 50 vpd. In terms of their extensive mileage, low-volume roads are clearly an important component of the highway transportation system. Low volume roads were found to experience a slightly higher percentage of injury accidents than the full sample of rural roads. In excess of one million accidents occur on these roads annually, resulting in 13,000 deaths and 600,000 injuries. Approximately 40 percent of the one million accidents involve run-off-the-road incidents. Proper guardrail installation could significantly lessen the severity of many of these accidents.

A guardrail is a type of longitudinal barrier used to shield motorists from natural or man-made hazards located along a roadway. Although a clear, unobstructed, flat roadside is highly desirable, one cannot always be attained. Roadside hazards that may require shielding by guardrail are categorized as embankments or roadside obstacles (nontraversable hazards and fixed objects). The guardrail itself is a hazard and should be installed only if it would reduce the severity of accidents. In other words, the guardrail must represent less of a hazard than the hazard being shielded. This is a very subjective guideline, however, and there are objective guidelines that can be employed to evaluate the need for guardrails. Commonly used guidelines are given in AASHTO's Roadside Design Guide published in 1996.

The Roadside Design Guide sets forth a process to identify hazards by a clear zone analysis and identification of non-crashworthy conditions. The final step of this process is to prioritize alternatives by their cost effectiveness. Typical alternatives are: 1) improve clear zone, 2) remove or relocate the hazard, 3) shield the hazard, and 4) accept the risk. Economic analysis is the primary consideration, but functional feasibility, agency policy, and available resources must be considered. Stretching available resources becomes extremely important for local governments with thousands of miles of low-volume roads. Although there are a multitude of sophisticated, computerized programs [such as ROADSIDE] that consider: 1) dimensions of the hazard, 2) location of the hazard, 3) severity Index of the hazard, 4) guardrail system and 5) ADT, they generally may not be useful to local government personnel.

Available guidelines generally apply to high-speed, high-volume roads. Under these guidelines it is not generally considered cost-effective to install guardrail on low-volume, low-speed roads. Local, low-volume road personnel need simpler, easier to use, more practical guidelines, albeit based on sound principles of risk vs. cost as addressed in many recent studies.

Objectives and Work Plan

The main objective of this study was to bring together the latest research and models on roadside hazard reduction, site-specific Kansas LVR conditions, accident cost, local government finances and practical common sense. Then to develop guidelines with easy to use charts, tables, etc., to guide LVR personnel to safe, cost-effective solutions, or a practical balance between least cost and "zero risk." The research effort consisted of the following basic tasks:

TASK 1: LITERATURE REVIEW. A comprehensive review of the research literature, as well as other information sources, was used to explore the use of guardrail on LVR. Selected transportation agencies in other states, as identified from the literature, were contacted to solicit specific information concerning their experiences regarding policies, procedures, and guidelines for installing guardrail on low-volume, low-speed roads. The purpose of these activities was to determine the need for guardrail on low-volume, low-speed roads and to uncover any specific guidelines already in use by other states.

TASK 2: DATA GATHERING. Based on TASK 1, and discussions with county personnel and the KDOT monitor, decisions were made on the variables that affect guardrail installation.

TASK 3: COST-EFFECTIVENESS ANALYSIS. A series of economic analysis using the ROADSIDE computer program for typical Kansas's low-volume road conditions was performed.

TASK 4: DEVELOP A LVR, ROADSIDE SAFETY GUIDELINES HANDBOOK. Based on the results of TASKS 1-3 and discussions with the KDOT Monitor and Advisory Committee, guidelines for guardrail on Kansas's low-volume roads were developed.

The results of the study tasks enumerated above are documented in the following chapters of this report.

2. PREVIOUS RESEARCH

Introduction

A comprehensive review of the research literature was conducted to explore and gather information on the use of guardrail on LVR according to safety and cost effectiveness. The purpose of this information search was to identify the general elements used to determine the need for guardrail on LVR and to review any specific guidelines already in use by other states in the USA. The principle findings from this literature review are presented below.

Existing Guidelines on LVR

Currently most states are using or developing guidelines for the installation of guardrail on state highways based on the Roadside Design Guide. Published by the American Association of State Highway and Transportation Officials (AASHTO, 1996) these AASHTO guidelines recommend guardrail if the consequences of hitting a roadside fixed object or running off the road would be more serious than those associated with striking the guardrail. The guidelines to warrant guardrail should consider two roadside conditions: embankment cross sections and fixed objects. The AASHTO guidelines do not have embankment warrants specifically for LVR due to the volume of traffic used and minimum foreslopes being better than typical LVR.

Guardrail Guidelines for Roadside Embankments

When considering the need for guardrail relative to roadside embankments, the height of the embankment and side slope are the principle physical factors used to make the decision. According to the Roadside Design Guide, a guardrail is warranted based on the fill section height and the reciprocal of the fill section slope, without considering the ADT (see Figure 1). Arnold (1990) mentions that several states use the Roadside Design Guide warrants directly, or in a modified form, regardless of ADT. However, some states already have guidelines, which additionally consider some other factors, with ADT being the most common. Some states do not install guardrail if the ADT is less than a certain value, e.g., <300. Some states usually do not install guardrail if the design speed is less than 65 km/h (40 mph). Others use engineering judgement based on a site visit.

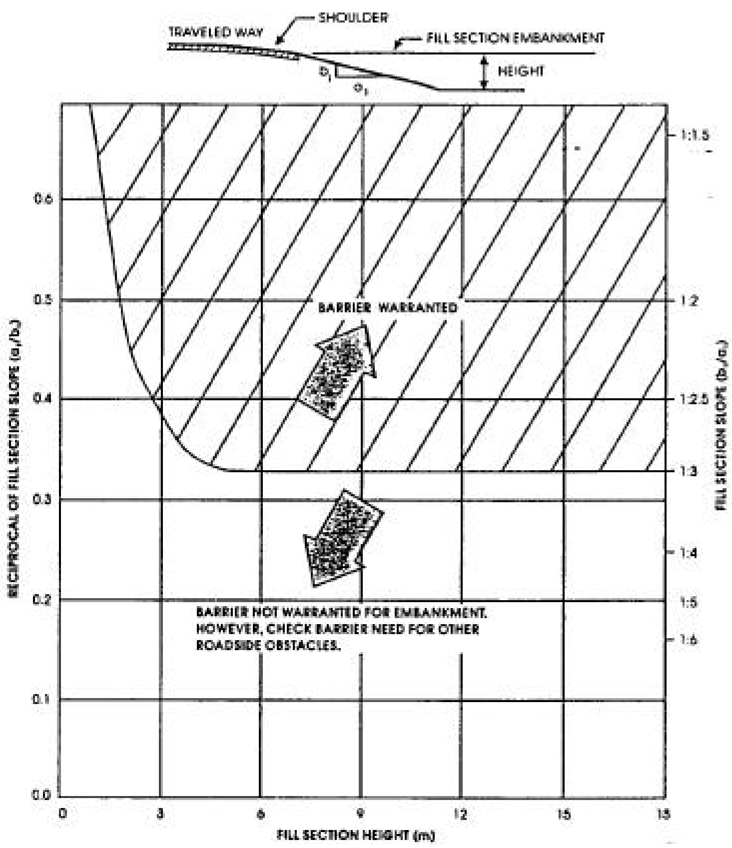


Figure 1. Roadside Design Guide warrants for roadside embankments (Source: Roadside Design Guide, 1996, p. 5-3).

Many states use the computer program ROADSIDE. However, this program has to be adapted for LVR. Some states have done this and developed curves and tables for LVR. An example of state embankment warrants for LVR is shown in Figure 2. As can be seen in Figure 2, for ADT of 400 and under, guardrail is warranted only if the embankment is over 15.2 meters (50 feet) high with a slope steeper than 1:2.

The state of North Carolina has similar warrants for LVR. North Carolina considers speed and the length of embankment. For example, for an ADT of 400, 88.2 km/h (55 mph) and a 1:2 1/2 slope, guardrail would be warranted on a 9.1 meter (30 foot) embankment if it were over 45.7 meters (150 feet) long, on a 6.1 meter (20 foot) embankment if it were over 305 meters (1,000 feet) long and on a 5.2 meter (17 foot) embankment if it were over 610 meters (2,000 feet) long.

The Arnold (1990) report presents guidelines to assist in evaluating the need for guardrail on secondary roads (generally ADT's ≤ 10,000) based on Virginia data, including a cost-effective analysis. The guidelines were presented in a series of warranting charts or figures based on fill height, slope, design speed and on traffic volume. Figure 3 shows an example of these charts.

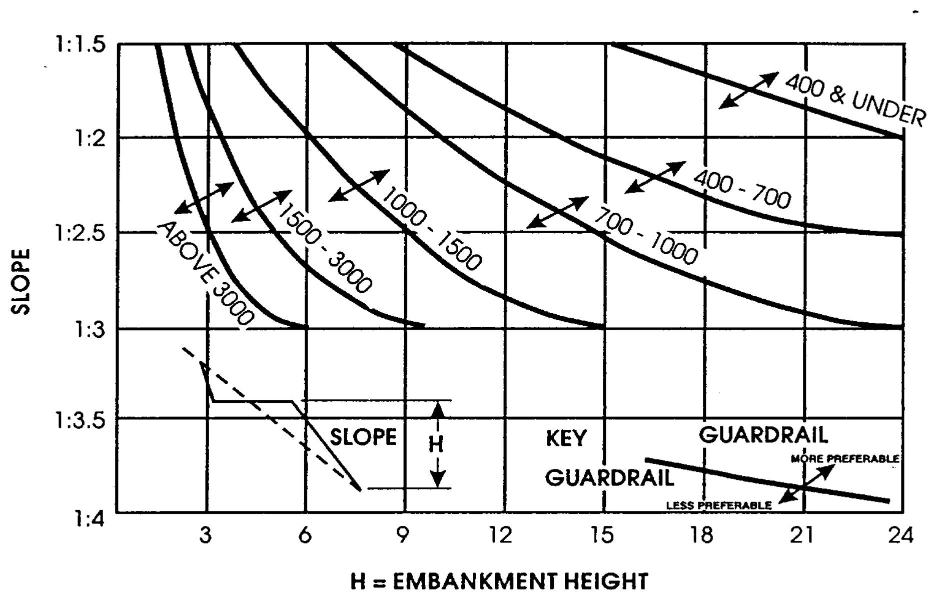


Figure 2. Georgia embankment warrants based on fill height and slope and on traffic volume (Source Roadside Design Guide, 1996).

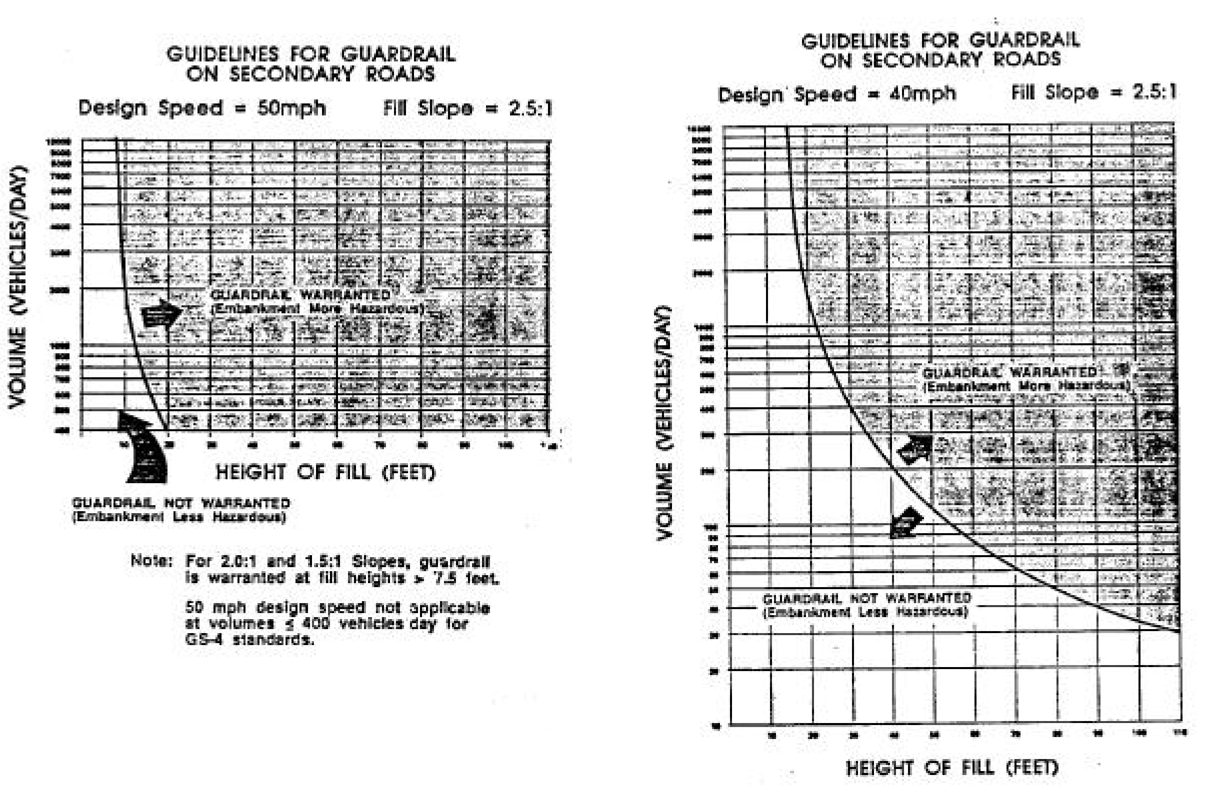


Figure 3. Example of the Virginia embankment warrants (Source: Arnold, 1990).

Missouri (Dare, 1992) developed guidelines for guardrail on LVR which considers the total life cycle cost of guardrail installations, physical characteristics of the hazard, severity or costs of accidents, and expected frequency of accident occurrence. For design speeds of 64 and 80 km/h (40 and 50 mph), guardrail installation was found to not be economically justified for any of the conditions used (slopes 1:2, 1:3, lateral offset of the hazard of 1.8, 2.4 and 3.0 meters (6, 8, and 10 feet)); and length of the hazard of 30.5, 152 and 305 meters (100, 500, and 1,000 feet) regardless of the embankment height, when the ADTs were lower than 400 vehicles. For design speed of 96 km/h (60 mph) the guardrail was warranted for ADTs between 350 and 400 vehicles only when the embankment height was of 6.1 meters (20 feet) for designs with cross slope of 1:2 or greater and certain combinations of lateral offset and length of the hazard: 1.8-30.5, 1.8-152, 1.8-305, 2.4-152, and 2.4-305 meters (6-100, 6-500, 6-1,000, 8-500, and 8-1.000 feet).

Guardrail Guidelines for Roadside Obstacles

Roadside obstacles may be nontraversable hazards or fixed objects and may be either man-made or natural. AASHTO has a classification for nontraversable and fixed objects which normally warrant shielding. These are general guidelines that call for judgement and do not specifically address LVR. They do state that shielding is generally required at bridge piers, abutments and railing ends, transverse ditches where probability of impact is high and non-breakaway supports close to the roadway.

There are two factors that have to be considered regarding the installation of guardrail for guarding against roadside obstacles: 1) the obstacle requiring guardrail and 2) the clear zone concept. According to the Roadside Design Guide, guardrail warrants for roadside obstacles are a function of the object itself and the probability that it will be hit.

The clear zone concept means having a traversable and unobstructed roadside zone from the edge of the traveled way that permits a high percentage of vehicles leaving the roadway out of control to recover. Figure 4 shows the clear zone distance curves developed by AASHTO.

Most states have followed the AASHTO guidelines (Roadside Design Guide, 1996) for roadside obstacles and clear zone distances. Arnold (1990), reported that 27 of 39 states contacted were using the AASHTO clear zone distances. Twelve states reported that they were using the AASHTO guidelines but with a policy that considered low-volume, low-speed roads. Exceptions to the AASHTO guidelines on LVR generally call for clear zone distances of 2.1 m (7 ft.) to 3.0 m (10 ft.) for ADT's between 400 and 750. Two states waive clear zone or do not install guardrail with design speed less than 64 km/h (40 mph) or ADT less than 300.

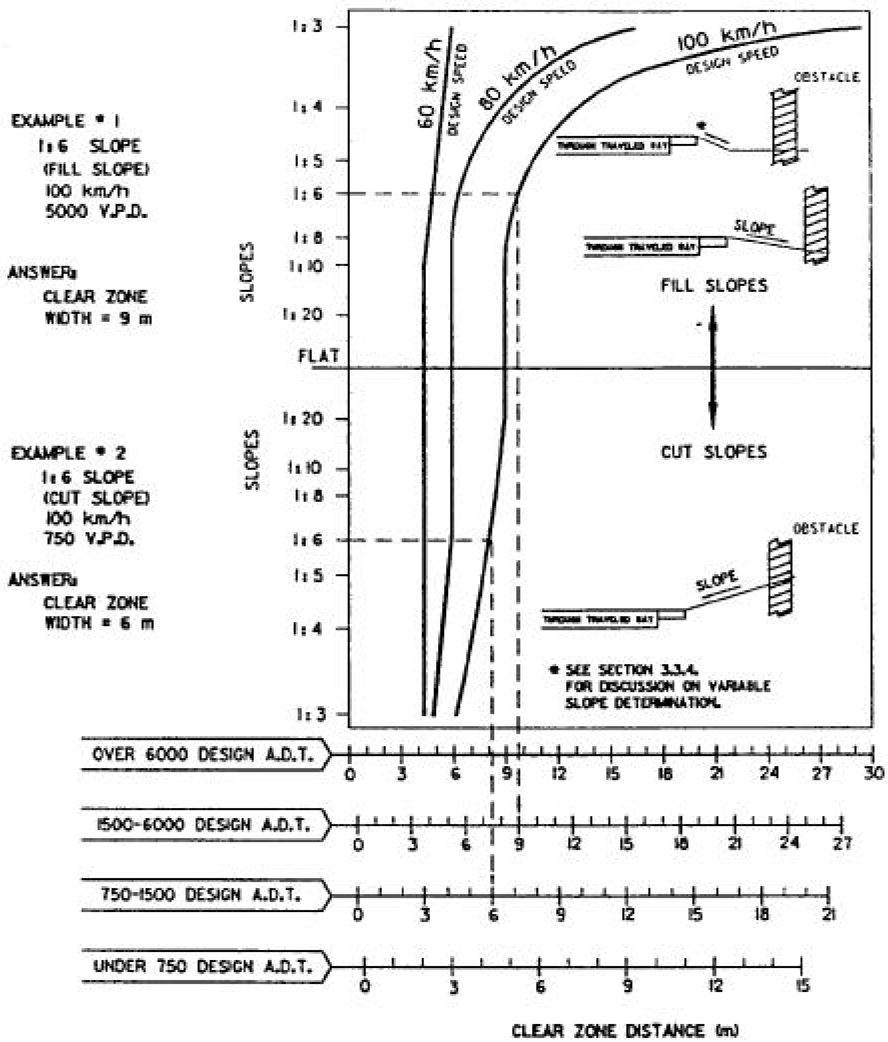


Figure 4. AASHTO clear zone distance curves (Source: Roadside Design Guide, 1996, p. 3-3).

In addition to the development of embankment warrants, Arnold (1990) defined new guidelines in terms of a required clear zone for fixed objects on secondary roads for the state of Virginia. Table 1 shows those guidelines.

Pigman and Agent (1990), discussed the development of warranting guidelines for clear zones in the state of Kentucky based on Kentucky accident severities. The computer program ROADSIDE was used to obtain the warranting guidelines. Table 2 presents some of these guidelines.

Table 1. Clear zones for LVR roads in the state of Virginia. Source: Arnold (1990).

Design Speed = 50 mph (81 km/h)		Design Speed = 40 mph (65 km/h)		Design Speed = 30 mph (48 km/h)	
ADT	Clear Zone (ft/m)	ADT	Clear Zone (ft/m)	ADT	Clear Zone (ft/m)
<475	5/1.5	<1,250	5/1.5	<8,000	5/1.5
575-525	6/1.8	1,250-1,400	6/1.8		
526-575	7/2.1	1,401-1,1650	7/2.1		
576-650	8/2.4	1,651-2,050	8/2.4		
651-750	9/2.7	2,051-2,400	9/2.7		
751-850	10/3.0	>2,400	10/3.0		
851-950	11/3.4				
951-1,075	12/3.7				
1.076-1,225	13/4.0				
1,226-1,375	14/4.3				
1.376-1,550	15/4.6				
1,551-1,775	16/4.9[1]				
1,776-2,075	17/5.2[2]				
2,076-2.375	18/5.5[3]				
2,376-2,700	19/5.8[3]				
>2,700	20/6.1[3]				

[1]Except 15 ft. (4.6 meters) in a cut.
[2] Except 15 ft. (4.6 meters) and an ADT <2,000.
[3] Except 17 ft. (5.2 meters) in a cut.

Table 2. Kentucky clear zone distances[1] (feet/meters). Source: Pigman and Agent (1990).

Traffic Volume (vpd)	TRAFFIC SPEED		
	40 mph/64 km/h	50 mph/80 km/h	60 mph/96 km/h
250	see footnote 2	3/0.91 (ft/m)[1]	12/3.7 (ft/m)[1]
500	see footnote 2	9/2.7 (ft/m)[1]	16/4.9 (ft/m)[1]

[1]The minimum clear zone distance needed without guardrail.
[2]An ADT of 700 was needed before a minimum 2 ft clear zone would be required.

Types of Guardrail Systems and Their Costs

Once the guardrail is warranted, the next problem that the local agencies face is to determine the type of guardrail needed for low volume, low speed roads. The AASHTO Roadside Design Guide (1996) describes a number of operational and experimental guardrail systems. Three of the operational systems that are currently being used in virtually all of the LVR applications throughout the USA are (Stephens, 1992): the G-1 cable systems, the G-2 weak post W-Beam, and the G-4 strong post W-beam. Examples of these are shown in Figures 5a, 5b and 5c, respectively. The G-1 and G-4 systems have variations in the type of post used.

Costs are presented in Table 3. Stephens (1993), presented the description of five low-service-level guardrail systems and the evaluation of those systems based on crash test and cost evaluations.

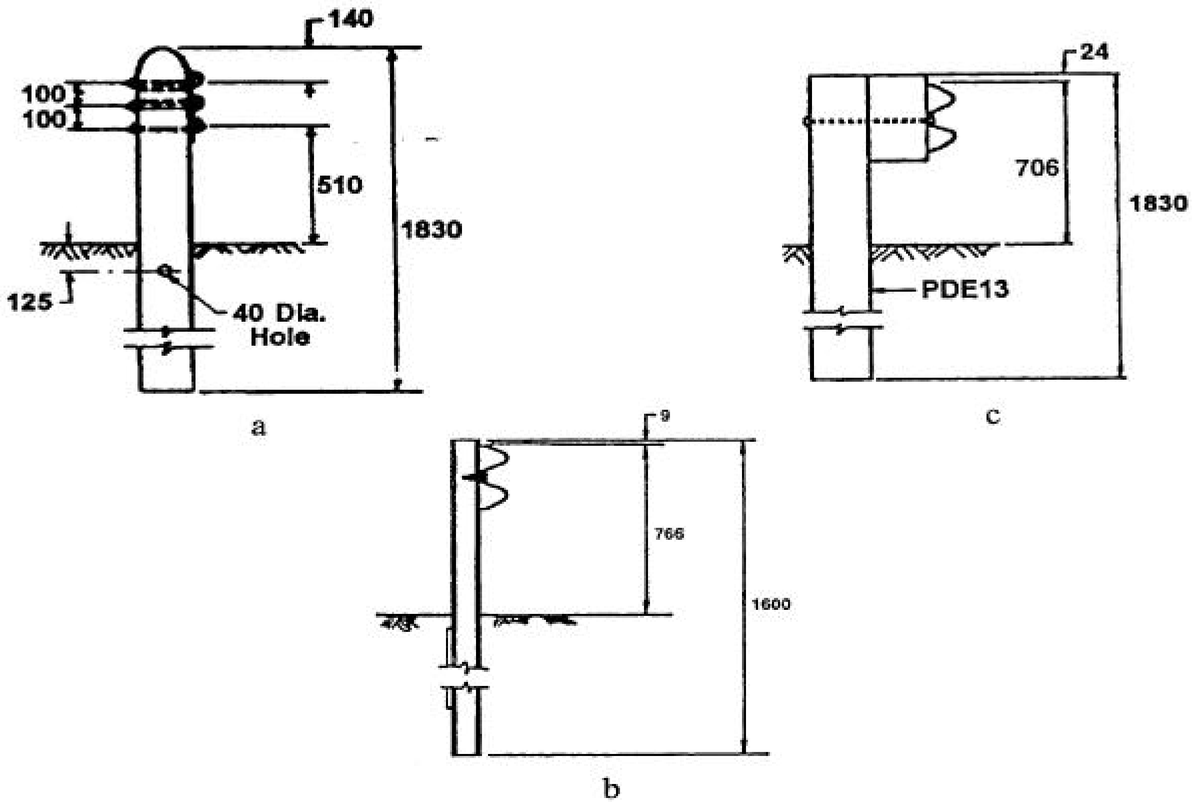


Figure 5. a: strand cable system (G - 1); b: w-beam (weak post) system (G - 2);
c: blocked out W-beam (strong post) system (G - 4) (Source: Roadside Design Guide, 1996).

In the Missouri study (Dare, 1992), installation costs were based on 1991 data. They were $700 for each Breakaway Cable Terminal (BCT) (two required) and $14.50/linear-ft ($47.5/linear meter) of Blocked-Out W-Beam (G-4) guardrail. Other costs reported were the repair costs: W-Beam = $250 average cost per collision and BCT end terminal = $600 average cost per collision.

Shultz et al. (1986), in the determination of the Pennsylvania guardrail standards used two type of guardrails: the weak post system (G-2) the strong post system (G-4). The reported installation costs were: weak-post (G-2) = $10.00/linear ft. ($32.8/linear meter) and the strong-post (G-4) = $16.50/linear ft ($54.12/linear meter).

Table 3. Guardrail Systems for LVR Roads and their associated costs. Source: Stephens (1993).

Code Guardrail. System	Beam	Post	% of Strong Post W-Beam (G-4)	Installation Cost[1]	End Treat. Cost[1]
GL-1	2 cables	4#/FT Steel	31%	$ 3.68/ft	$1,040.00
G-2[2]	W-Beam	S3x5.7 Steel	64%	$ 7.63/ft	$1,250.00
G-4	W-Beam	8"x8" Wood 6"x8" Wood W6x8.5 Steel "C" Steel	100%	$ 11.85/ft	$1,650.00

Other costs:

Repair Costs:

W-Beam Systems		$210 average cost per collision
Cable Systems		$270 average cost per collision
End treatments:		
	BCT for G-4	$410
	GL-4, GL-5, G-2 $310	$310
	G-1	$350
	GL-1, GL-2, Gl-3 $260	

Maintenance costs and salvage value = 0

[1] Money values from 1990.
[2] Virginia reports the following costs for G-2 (Arnold, 1990): Installation cost = $9.61/ft ($31.52/meter); End treatment cost = $700 (money values July 1, 1987 to March 1, 1989); Repair costs = $500 per collision.

Approaches for Performing Guardrail Assessments

Stephens (1993) stated that due to the variety of possible conditions on low-volume roads, standard warrants (generally developed for high speed, high volume) are impractical. He presented a warranting procedure that is intended to assist low-volume road practitioners in determining if hazards exist, to evaluate alternatives, and if guardrail is warranted, to select the most cost-effective system. The report recommends that a framework for evaluating hazards and treatment alternatives considering local conditions, policies, and resources be used. The framework gives two general processes: 1) a hazard identification process, and 2) an approach for evaluating alternatives.

The hazard identification process starts with the identification and estimation of the severity of hazards. Then it suggests that a classification of the physical attributes of the hazard is necessary to evaluate treatment alternatives. Finally, the information on accident history must be considered if available.

Although the Roadside Design Guide (1996), presents warrants for determining the need for guardrail based on embankment and roadside obstacle criteria, the recommendation was made by AASHTO that highway agencies develop specific guidelines for their agency based on a cost-effectiveness selection procedure based on the application of the computer program ROADSIDE. *ROADSIDE* allows the user to calculate the present worth and annualized cost (including accidents, installation, repair and maintenance) of a specific safety improvement at a specific location. The real value of the program is that it allows a cost comparison of alternative improvements (including the do-nothing alternative).

The procedure to evaluate alternatives should be based on a cost-effectiveness analysis with or without the ROADSIDE computer program. It should consider all possible treatment alternatives.

3. COST-EFFECTIVENESS ANALYSIS

Introduction

Based on the literature review and AASHTO's recommendation to use cost-benefit analysis to warrant guardrail, Kansas-specific guidelines for embankments and for fixed objects were developed. These guidelines were based on application of the microcomputer program ROADSIDE, which is documented in Appendix A of AASHTO's Roadside Design Guide (American Association of State Highway and Transportation Officials, 1996).

ROADSIDE, a computerized economic analysis procedure, is intended to assure that guardrail is installed only in those places where it will provide a meaningful benefit to the motoring public and make judicious use of limited highway funds.

ROADSIDE, Version 5.0, was used in the cost-effectiveness analysis to compare the cost of installing guardrail with the cost of doing nothing. The cost of the guardrail included the initial cost, repair cost, maintenance cost, and the cost of predicted collisions with the guardrail. The do-nothing cost included the cost of collisions with a fixed object or with a fill embankment. The guardrail was recommended if its costs were less than the do-nothing costs.

Threshold, or recommended values, were defined as points at which the cost of guardrail equaled the cost of doing nothing as certain parameters were varied in ROADSIDE.

For the accident cost on embankments, the design speed, slope, height of fill, and traffic volume were varied and guardrail was recommended when the accident costs of running down the embankment was equal to or greater than the guardrail cost. From the break-even point, an increase in ADT, height of fill, or steepness of slope resulted in the do-nothing alternative being more expensive than the installation of guardrail (including associated accident costs).

In the case of fixed objects along the roadside, the design speed, distance of the object from the edge of the roadway, and traffic volume were varied, and guardrail became economically justifiable when the accident costs of colliding with the fixed object was equal to or exceeded the guardrail cost. From the break-even point, increasing the ADT or locating the object closer to the roadway resulted in the do-nothing alternative being more expensive than the installation of guardrail (including associated accident costs).

Procedures Used in Applying ROADSIDE

The procedures used and the assumptions made in applying ROADSIDE will be explained in terms of the three input screens in the program (Figure 6 through 8). Table 4 provides a summary of parameters used for cost-effectiveness analysis.

Figure 6 is the first screen in ROADSIDE and indicates the basic input data and global values used in the program. Figure 6 shows the values used for the guardrail analysis which were obtained from KDOT. The default encroachment model, item 7, was changed to the encroachment model suggested by Stephens (1992) for low ADT ranges (ADT < 3,000).

Figure 7 is the second screen in ROADSIDE and relates the severity index (SI) to the cost of an accident. The SI was established on a scale of 0 to 10 by the developers of ROADSIDE, with 0 representing an accident with no significant property damage or injury, and 10 representing an accident with a 100% chance of a fatality. Numbers within the scale represent an assumed percentage distribution among the accident severity levels shown in Figure 7.

1. FATAL ACCIDENT COST = $ 2,672,900
2. SEVERE INJURY ACCIDENT COST = $ 185,050
3. MODERATE INJURY ACCIDENT COST = $ 37,000
4. SLIGHT INJURY ACCIDENT COST = $ 19,550
5. PDO LEVEL 2 ACCIDENT COST = $ 2,050
6. PDO LEVEL 1 ACCIDENT COST = $ 650
7. ENCROACHMENT RATE = 0.0010354 ENCROACHMENTS/km/YR/VPD
8. 50 km/h DES SPEED ENC ANGLE = 13.0 DEG AND TRAF VOL CAP =10,000 VPD/LANE
9. 60 km/h DES SPEED ENC ANGLE = 12.8 DEG AND TRAF VOL CAP =10,000 VPD/LANE
10. 70 km/h DES SPEED ENC ANGLE = 12.4 DEG AND TRAF VOL CAP =10,000 VPD/LANE
11. 80 km/h DES SPEED ENC ANGLE = 12.0 DEG AND TRAF VOL CAP =10,000 VPD/LANE
12. 90 km/h DES SPEED ENC ANGLE = 11.6 DEG AND TRAF VOL CAP =10,000 VPD/LANE
13. 100 km/h DES SPEED ENC ANGLE = 11.1 DEG AND TRAF VOL CAP =10,000 VPD/LANE
14. 110 km/h DES SPEED ENC ANGLE = 10.7 DEG AND TRAF VOL CAP =10,000 VPD/LANE
15. 120 km/h DES SPEED ENC ANGLE = 10.3 DEG AND TRAF VOL CAP =10,000 VPD/LANE
16. SWATH WIDTH = 3.600 m

Figure 6. ROADSIDE basic input data and global values.

SEVERITY INDEX	COST
0.0	$ 0
0.5	$ 650
1.0	$ 3,198
2.0	$ 8,347
3.0	$ 43,878
4.0	$ 107,760
5.0	$ 253,596
6.0	$ 535,834
7.0	$ 869,741
8.0	$ 1,394,226
9.0	$ 2,040,574
10.0	$ 2,672,900

Figure 7. ROADSIDE severity index and accident cost relationship.

Figure 8 is the third screen in ROADSIDE and allows input of the variable data specified to an alternative being evaluated. Following is a discussion of how each of the items 2 through 15 was derived in applying ROADSIDE in the embankment and fixed object analyses:

Item 2. Traffic Volume. The traffic volume varied between 400 vehicles per day (vpd) to 100 vpd in both analyses with a constant growth factor of 1% per year.

Item 3. Roadway Type. A two-lane, two-way road was used for both analyses by setting an undivided roadway with one lane adjacent to the hazard in ROADSIDE. The lane width was assumed 3 meters.

Item 4. Adjustment Factors. ROADSIDE allows adjustment to the baseline encroachment to account for roadway curvature and grade. For both analyses, a value of 1.0 was used.

Item 5. Traffic Volume and Encroachments. ROADSIDE calculates this item by assuming splitting of the previously input traffic volume evenly by direction, applying the encroachment defined earlier, and adjusting the baseline encroachment by the factors in item 4.

Item 6. Design Speed and Encroachment Angle. The following speeds were used in the calculations: 50, 60, 70, 80 and 90 km/h. The default encroachment angles shown in Figure 6 were used in the analyses.

Item 7. Hazard Definition. In ROADSIDE, a hazard 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.

Lateral Offset

On Kansas unpaved rural roads, there is no way to describe or show a typical section of where to measure the offset from. This must be determined in the field. Depending upon local blading practices, the usable roadway width (traveled way) may vary from one local jurisdiction to another and in fact may vary from before and after a section is bladed. The only practical solution is for the person in charge of road and street operation and maintenance to determine and record the outer limits of the normal traveled way. This could vary from the edge of wheel paths on class C primitive (LVR Handbook) roads with two clearly defined wheel paths to the outer limits of the bladed (and usable) surface on class B or class A gravel roads. In summary, it depends upon how a gravel road surface is bladed and how it is normally driven (in relation to the usual outer limit of vehicle positioning) and this can only be determined by field observation and judgement.

```
 1.   TITLE:  STARTUP VALUES

 2.   INITIAL TRAFFIC VOLUME       =    400 VEHICLES PER DAY
      TRAFFIC GROWTH RATE          =    1.000 %/YEAR      UNCAPPED DES YR ADT   =     488 VPD
      TRAFFIC GROWTH RATE          =    22,800  VPD/LANE       AT 476.0 YR  RND TO 476 YR

 3.   UNDIVIDED HIGHWAY     TOTAL LANE(S)  =     2           LANE WIDTH  =   3.00  m

 4.   CURVATURE  (RADIUS IN METERS)      =    9,999          GRADE   (PERCENT)      =   0.0

 5.   INITIAL ENCROACHMENT FREQUENCY       =    0.0010354 *  (TVeff)  ENC/km/YR
                EFFECTIVE        BASELINE         CURVATURE       GRADES  USER           TOTAL
              TRAFFIC VPD       ENC/km/YR           FACTOR        FACTOR      FACTOR      ENC/km/YR
ADJACENT            200            0.2071              1.00           1.00          1.00          0.2071
OPPOSING            200            0.2071              1.00           1.00          1.00          0.2071

 6.   DESIGN SPEED    =    90 km/h   ENC ANGLE  =    11.6 DEG      SWATH WIDTH    =    3.60 m

 7.   LATERAL OFFSET (A)         =    0.30 m
      LONGITUDINAL LENGTH (L)    =    6.00 m
      WIDTH OF OBSTACLE (W) =    0.30 m
                                  ZONE 1             ZONE 2             ZONE 3
      ADJACENT                    0.0003             0.0037             0.0012         ENCROACHMENTS/YEAR
      OPPOSING                    0.0003             0.0037             0.0012         ENCROACHMENTS/YEAR


 8.   INITIAL COLLISION FREQUENCY    =     0.00524  IMPACTS PER YEAR
      ADJACENT   CFTA     =    0.0035   CFSU      =    0.0001    CFCU     =    0.0022    CFFA     =    0.0011
      OPPOSING   CFTA     =    0.0018   CFSD      =    0.0001    CFCD     =    0.0012    CFFO     =    0.0005
      EXPECTED IMPACTS OVER PROJECT LIFE   =    0.116

 9.   SEVERITY INDEX       SU   =    4.00        SD   =    4.20        CU   =    4.70        CD   =    5.30        FACE      =    5.70
      ACCIDENT COST        $    107,760          $    136,927          $    209,845          $    338,267          $ 451,162
         INITIAL COST/YEAR   IMPACTS WITH UPSTREAM SIDE              OF FEATURE =    $       13
         INITIAL COST/YEAR   IMPACTS WITH DOWNSTREAM SIDE            OF FEATURE =    $        9
         INITIAL COST/YEAR   IMPACTS WITH UPSTREAM CORNER            OF FEATURE =    $      460
         INITIAL COST/YEAR   IMPACTS WITH DOWNSTREAM CORNER          OF FEATURE =    $      400
         INITIAL COST/YEAR   IMPACTS WITH FACE                       OF FEATURE =    $      761
                                      TOTAL INITIAL ANNUAL ACCIDENT COST                 =    $    1,642

10.   PROJECT LIFE     =    20 YEARS          DISCOUNT RATE =    4.000 %/YR
      CRF   =   0.07358         KC   =    14.84437        KT   =     13.59033        KJ    =     0.45639

11.   INSTALLATION COST =    $     450             SALVAGE VALUE       =    $           0

12.   REPAIR COST/ACC  $  SU  =           500         SD  =       500         CU  =       500         CD  =       500         F  =         500

13.   MAINTENANCE COST PER YEAR           =    $           18

14.   TOTAL PRESENT WORTH                 =    $      25,113          ANNUALIZED       $      1,848
         ACCIDENT COST                    =    $      24,379          ANNUALIZED       $      1,794
         HIGHWAY DEPARTMENT COST          =    $         734          ANNUALIZED       $         54
            INSTALLATION COST        =    $        450          ANNUALIZED      $         33
            REPAIR COSTS                  =    $          39          ANNUALIZED       $          3
            MAINTENANCE COST         =    $        245          ANNUALIZED      $         18
            SALVAGE VALUE                 =    $           0          ANNUALIZED       $          0
```

Figure 8. ROADSIDE variable input data and cost calculations.

The following parameters were used in the analyses:

<u>For embankment analysis</u>: In the embankment analysis, 60 m (200 ft) was used for the length of both the guardrail and the embankment. Different lengths were tested, and 60 m yielded the smallest height of fill at which guardrail became cost-effective. Thus, this value is conservative on the side of safety.

Length: 60 m (200 ft.) for both (guard and embankment)
6 m (20 ft.) on culverts
Width of guardrail: 0.3 m (1 ft.)
Width of embankment: variable depending on embankment height and cross slope.
Foreslopes: 1:2, 1:3, 1:4
Height: 0 to 10 m (0 to 32.8 ft.)
Lateral offset for guardrail:
0.0, 0.3, 1, 3, 5 m
Lateral offset for embankment:
3 m (10 ft)

<u>For the fixed objects analysis</u>: For the fixed objects analysis a 60 m (200 ft) section of guardrail was compared with a 0.3 m (1 ft) by 0.3 m (1 ft) fixed object.
Length: 0.3 m (1 ft.)
Width: 0.3 m (1 ft.)
Lateral offset of the fixed objects:
0, 0.3, 1, 2, 3, 5 m

Item 8. Initial Collision Frequency. These values are calculated by ROADSIDE based on previously input data.

Item 9. Severity Index. Severity indexes, (SIs) are estimates of the societal costs associated with an average accident with a given feature. ROADSIDE uses the SIs to determine the cost of accidents. Five values are needed to perform the analyses. One for each: the upstream side, the upstream corner, the force, the downstream corner, and the downstream side of the texture. For both, embankment analysis and fixed objects analysis, the SIs used were taken from the Appendix A: *A Cost-Effectiveness Selection Procedure; a user's guide and documentation for the computer program ROADSIDE.*

Item 10. Project Life and Discount Rate. For the purpose of this project, an anticipated life of 20 years and a discount rate of 4 percent were used.

Item 11. Installation Cost. Based on the data provided by KDOT the installation cost was $82.50 linear meter ($25 per linear foot) for G4 (2W) - 6" x 8" (15.3 cm x 2-.3 cm) wood.

Item 12. Repair Cost/Accident. For the purpose of this project, $500 was used as the average cost of repairing hit guardrail.

Item 13. Maintenance Cost/Year. Based on the data provided by KDOT, the maintenance cost was $ 3.00 per linear meter ($1.00 per linear foot)

Item 14. Salvage Value. For the purpose of this project, the salvage value was assumed to equal $0.

Item 15. Present Worth/Highway Department Costs. ROADSIDE calculates the total present worth (TPW) of accident costs and highway department costs incurred over a specified analysis period (the project life) using the following equation:

TPW = CA (KC) + CI + ARC + CM(KT) - CS(KJ)

Where:

- CA - Accident cost based on initial collision frequency
- KC - Factor to account for project life, discount rate, and traffic growth rate
- CI - Installation cost
- ARC - Present worth of accident report cost = SKC(CDi) (CFi)
  - CDi - Average collision damage repair costs for sides, corners, and face
  - CFi - Initial collision frequencies for sides, corners, and face
- CM - Annual maintenance cost
- KT - Factor to account for the project life and the discount rate
- CS - Salvage value of feature being studied
- KJ - Factor to account for the project life and the discount rate

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

Table 4. Summary of Parameters Used for the Kansas Study, Cost-Effectiveness Analysis Using "ROADSIDE".

Costs by Severity Level	Encroachment Rate	Enc. Angle and Traffic Vol. Cap	Swath Width
Based on FHWA's Tech. Adv. Dated October 31, 1994. Costs are also based on the change of the Consumer Price Index from January 1994 (146.2) to January 1995 (150.3). Fatality $2,672,900 Severe Injury $ 185,000 Moderate Injury $ 37,000 Slight Injury $ 19,550 PDO Level 2 $ 2,050 PDO Level 1 $ 650	Based on encroachment model suggested by Stephens (1992) for low ADT ranges (ADT < 3,000). The encroachment rate was originally recommended in the AASHTO's 1977 *Guide for Selecting, Locating and Designing Traffic Barriers.* Enc. Rate = 0.001035424 * (ADT) enc/km/yr Or Enc. Rate = 0.00166 * (ADT) enc/mi/yr	ROADSIDE default values: Encroachment angle at 50 km/h (30 mph) = 13 Encroachment angle at 60 km/h (35 mph) = 12.8 Encroachment angle at 70 km/h (45 mph) = 12.4 Encroachment angle at 80 km/h (50 mph) = 12.0 Encroachment angle at 90 km/h (55 mph) = 11.6 Traffic Volume Cap per lane = 10,000/day	ROADSIDE default value: 3.6 m (12 ft)

Parameter	Feature Location/Size	Severity Indices	Project Life/Disc. Rate	Installation/Salvage/Repair/Maintenance Costs
Values	For embankment analysis: *Length:* 60 m (200 ft.) for both (guard and embankment) 6 m (20 ft.) on culverts *Width of guardrail:* 0.3 m (1 ft.) *Width of embankment:* variable depending on embankment height and cross slope. *Foreslopes:* 1:2, 1:3, 1:4 *Height:* 0 to 10 m (0 to 32.8 ft.) *Lateral offset for guardrail:* 0.0, 0.3, 1, 2, 3, 5 m *Lateral offset for embankment:* 3 m (10 ft) For the fixed objects analysis: *Length*: 0.3 m (1 ft.) *Width*: 0.3 m (1 ft.) *Lateral offset of the fixed objects:* 0, 0.3, 1, 2, 3, 5 m	For both, embankment analysis and fixed objects analysis. The Severity Indices used were taken from the Appendix A: *A Cost-Effectiveness Selection Procedure; a user's guide and documentation for the computer program ROADSIDE.*	Project life: 20 yrs. Discount rate: 4%	Guardrail System considered: G4 (2w) - 6" x 8" Wood G4 (1s) - W6 x 8.5 Steel Installation Cost: $82.5/lin m ($25.00/lin ft.) End treatment: $0.00 Repair Cost: $500/accident Maintenance Cost: $3.00/lin/m ($1.00/lin ft.) Salvage Value: $0.00

Parameter	Traffic Volume/Growth Rate	Highway Type/Lane Width	Curvature/Grade	User Encroachment	Design Speed
Values	Volume: 100 vpd, 200 vpd, 300 vpd, 400 vpd Growth Rate: 1%	Two-lane, two-way Undivided roadway. Lane Width: 3 m (10 ft)	No adjustment factors were used (value of 1 for all three)	No factors were used	50, 60, 70, 80, and 90 km/h or 30, 35, 45, 50, and 55 mph

Codes: ft = feet; m = meters; mi = mile; km = kilometers; vpd = vehicles per day; enc = encroachments; yr = year; PDO = Property Damage Only; ADT = Average Daily Traffic; mph = miles per hour; km/h = kilometers per hour

Note: 0.3048 m = 1 ft 1.609 km = 1 mi 1.609 km/h = 1 mph

4. RESULTS

Results are from a cost-effectiveness analysis based on several assumptions, which are either input into the ROADSIDE program or inherent within the program; therefore, the results should be used with judgement after considering other, non-economic factors.

Roadside Obstacle

RCB Culvert - Straight Wings (Figure 9). Based on the total life cycle cost analysis, the guardrail was economically justifiable for speeds of 90 km/h, ADTs of 300 or higher and culvert end height of 2.4 meters. For details see Table 5 and Appendix A. The results indicated that the guardrail was not economically justified if the culvert's lateral offset from the nearest driving lane was two or more meters.

RCB Culvert - Flared Wings (Figure 10). The study results indicated that, under all conditions, guardrail was not economically justified if the culvert's lateral offset from the edge of the nearest driving lane was more than three meters. For some other conditions, installation of guardrail was economically justifiable. Details are presented in Table 6 and Appendix A.

RCP Culvert - Pipe/Headwall (Figure 11). The study results indicated that the guardrail was not economically justified if the average daily traffic was less than 100. Guardrail was economically justifiable for some other conditions. Details are presented in Table 7 and Appendix A.

Utility Poles. For this analysis, a 60 m (200 ft) section of guardrail was compared with 0.3 m (1 ft) by 0.3 m (1 ft) utility pole. The probability of a vehicle striking a 60 m (200 ft) length of guardrail in ROADSIDE is so much greater than that of striking a 0.3 m (1 ft) long object that guardrail is almost always much more expensive and therefore almost never recommended. Details are presented in Table 8 and Appendix B.

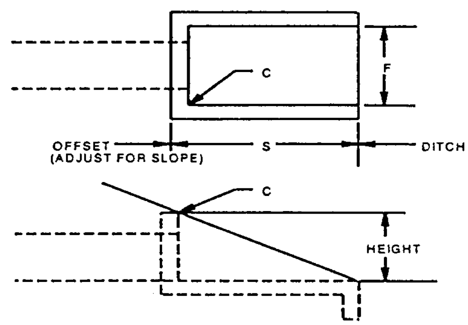
Embankments

The study results concerning guardrail installation on roadside embankments indicated that the guardrail was not economically justified for either 1:4 or 1:3 foreslopes with slope surface condition B, regardless of the design speed and ADT. For 1:3 foreslopes with slope surface condition C, ADT of 400, speed of 90km/h and height of fill of four or more meters, installation of the guardrail was economically justifiable. Guardrail was economically justifiable on most 1:2 foreslopes with surface condition B and C. Details, including definitions of surface conditions B and C, are presented in Table 9 and Appendix C.

Conclusions

Application of the ROADSIDE microcomputer program produced valuable results that should provide for a more cost-effective use of guardrail on rural, low-volume roads in Kansas. It is important to note that the procedures and input parameters used in this study were based on the latest information available at the time. Also, considerations beyond cost-effectiveness may be important.

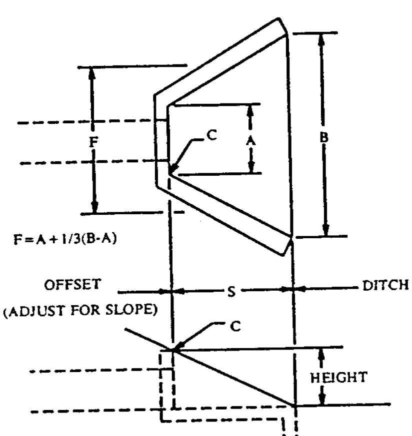
Culvert Ends:
Culvert Axis Transverse to traffic
Culvert End Type D
(See sketch below.)



S = Approach Side, C = Corner, F = Traffic Face

Figure 9. RCB Culvert - Straight Wings (*Roadside Design Guide*, 1996, p. A-87)

Culvert Ends:
Culvert Axis Transverse to traffic
Culvert End Type E
(See sketch below.)



S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

Figure 10. RCB Culvert - Flared Wings (*Roadside Design Guide*, 1996, p. A-88)

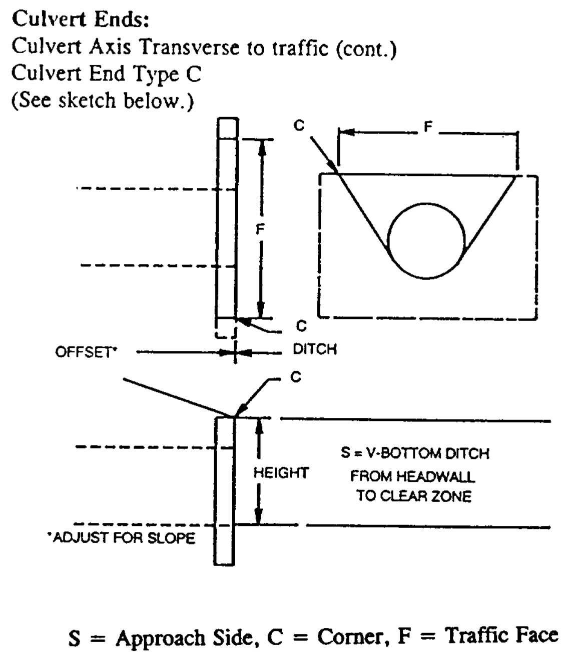


Figure 11. RCP Culvert - Pipe/Headwall (Roadside Design Guide, 1996, p. A-86)

Recommendations

The guidelines for guardrail developed in this study should be used by counties when considering the need for guardrail at specific locations on their rural, low-volume roads.

1. Tables 5, 6, 7 and 8 and Appendix A and B should be consulted for roadside obstacles when evaluating a need for guardrail.

2. Specifically, Table 9 and Appendix C should be consulted for guardrail on a fill embankment.

Table 5. Guidelines for Guardrails on LVR; RCB CULVERT--Straight Wings

OFFSET (in meters)	ADT	400	300	200	100
	Speed (km/h)	Breakeven Culvert End Height			
0.0	50 60 70 80 90	NR NR NR NR **2.4 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR	NR NR NR NR NR
0.3	50 60 70 80 90	NR NR NR NR **2.4 m**	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
1.0	50 60 70 80 90	NR NR NR NR **2.4 m**	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
2.0	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
3.0	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
5.0	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR

m - meters
NR - Guardrail not recommended based on cost-effectiveness analysis
OFFSET - a lateral distance from the edge of the roadway to the culvert (See Figure 9)

Table 6. Guidelines for Guardrails on LVR; RCB CULVERT--Flared Wings

OFFSET (in meters)	ADT	400	300	200	100
	Speed (km/h)	Breakeven Culvert End Height			
0.0	50	NR	NR	NR	NR
	60	**2.4 m**	**2.4 m**	NR	NR
	70	**1.8 m**	**2.4 m**	NR	NR
	80	**1.8 m**	**2.4 m**	**2.4 m**	NR
	90	**1.8 m**	**1.8 m**	**2.4 m**	NR
0.3	50	NR	NR	NR	NR
	60	**2.4 m**	NR	NR	NR
	70	**2.4 m**	**2.4 m**	NR	NR
	80	**1.8 m**	**2.4 m**	NR	NR
	90	**1.8 m**	**1.8 m**	**2.4 m**	NR
1.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	**2.4 m**	NR	NR	NR
	80	**2.4 m**	**2.4 m**	NR	NR
	90	**1.8 m**	**2.4 m**	**2.4 m**	NR
2.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	**2.4 m**	NR	NR	NR
	80	**2.4 m**	**2.4 m**	NR	NR
	90	**1.8 m**	**2.4 m**	NR	NR
3.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	**2.4 m**	NR	NR	NR
	90	**2.4 m**	**2.4 m**	NR	NR
5.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR

m - meters
NR - Guardrail not recommended based on cost-effectiveness analysis
OFFSET - a lateral distance from the edge of the roadway to the culvert (See Figure 10)

Table 7. Guidelines for Guardrails on LVR; RCP CULVERT--Pipe/Headwall

OFFSET (in meters)	ADT	400	300	200	100
	Speed (km/h)	Breakeven Culvert End Height			
0.0	50 60 70 80 90	**2.4 m** **1.8 m** **1.8 m** **1.0 m** **1.0 m**	**2.4 m** **2.4 m** **1.8 m** **1.8 m** **1.2 m**	NR **2.4 m** **2.4 m** **1.8 m** **1.8 m**	NR NR NR NR NR
0.3	50 60 70 80 90	**2.4 m** **1.8 m** **1.8 m** **1.2 m** **1.0 m**	NR **2.4 m** **1.8 m** **1.8 m** **1.2 m**	NR NR **2.4 m** **1.8 m** **1.8 m**	NR NR NR NR NR
1.0	50 60 70 80 90	NR **2.4 m** **2.4 m** **1.8 m** **1.2 m**	NR **2.4 m** **2.4 m** **1.8 m** **1.2 m**	NR NR NR **2.4 m** **1.8 m**	NR NR NR NR NR
2.0	50 60 70 80 90	NR **2.4 m** **2.4 m** **1.8 m** **1.2 m**	NR NR **2.4 m** **1.8 m** **1.8 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR
3.0	50 60 70 80 90	NR NR **2.4 m** **1.8 m** **1.8 m**	NR NR NR **2.4 m** **1.8 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR
5.0	50 60 70 80 90	NR NR NR **2.4 m** **1.8 m**	NR NR NR NR **2.4 m**	NR NR NR NR **2.4 m**	NR NR NR NR NR

m - meters
NR - Guardrail not recommended based on cost-effectiveness analysis
OFFSET - a lateral distance from the edge of the roadway to the culvert (See Figure 11)

Table 8. Guidelines for Guardrail on LVR; UTILITY POLES

OFFSET (in meters	ADT	400	300	200	100
	Speed (km/h)	Breakeven Cost			
0.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	**R**	NR	NR	NR
0.3	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	**R**	NR	NR	NR
1.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
2.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
3.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR
5.0	50	NR	NR	NR	NR
	60	NR	NR	NR	NR
	70	NR	NR	NR	NR
	80	NR	NR	NR	NR
	90	NR	NR	NR	NR

NR - Guardrail not recommended based on cost-effectiveness
R - Guardrail is recommended based on cost analysis
OFFSET - a lateral distance from the edge of the roadway to the utility pole

Table 9. Guidelines for Guardrail on LVR; SLOPES--Foreslope 1 to 2, 1 to 3 and 1 to 4

SLOPES	ADT	400	300	200	100
	Speed (km/h)	Breakeven Height of Fill			
Foreslope 1 to 2 Slope Condition B	50 60 70 80 90	NR **8.0 m** **6.0 m** **2.0 m** **2.0 m**	NR **10.0 m** **8.0 m** **4.0 m** **2.0 m**	NR NR **10.0 m** **4.0 m** **4.0 m**	NR NR NR NR NR
Foreslope 1 to 3 Slope Condition B	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
Foreslope 1 to 4 Slope Condition B	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
Foreslope 1 to 2 Slope Condition C	50 60 70 80 90	**10.0 m** **8.0 m** **2.0 m** **2.0 m** **2.0 m**	NR **8.0 m** **6.0 m** **2.0 m** **2.0 m**	NR NR **6.0 m** **2.0 m** **2.0 m**	NR NR NR **10.0 m** **4.0 m**
Foreslope 1 to 3 Slope Condition C	50 60 70 80 90	NR NR NR NR **4.0 m**	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR
Foreslope 1 to 4 Slope Condition C	50 60 70 80 90	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR	NR NR NR NR NR

Slope surface Condition
B: Smooth but subject to deep rutting by errant vehicles half of the year.
C: Shallow gullies (100 to 200 mm deep), scattered small boulders (under 225 mm projections), scattered small trees (diameters 75 to 100 mm), or structurally substantial woody brush. Features spaced so that nearly all encroaching vehicles will encounter them.
m - meters
NR - Guardrail not recommended based on cost-effectiveness analysis

5. REFERENCES

Roadside Design Guide. American Association of State Highway and Transportation Officials, Washington, D.C., 1996.

Summary Report on Selected Guardrails, Report No. FHWA-SA-91-050, Federal Highway Administration, Washington, D.C., June 1992.

Arnold, E.D., *Guidelines for Guardrail on Low-Volume Roads,* Report No. 91-R15, Virginia Transportation Research Council, Charlottesville, Virginia, November 1990.

Dare, C.E., *Guidelines for Guard Rail Installation on Embankments and Bridge Ends: Low-Volume Roads in Missouri*, Final Report 91-2, Missouri Cooperative Highway Research Program, Missouri Highway and Transportation Department, December 1992.

Pigman, J.G. and Agent, K.R., *Guidelines for Installation of Guardrail.* In: Transportation Research Record 1302, Transportation Research Board, National Research Council, Washington, D.C., 1991, pp. 24-31.

Schultz, L.C. et al., *Pennsylvania's Guide Rail Standards: A Cost-Effective Change*. In: Transportation Research Record 1065, Transportation Research Board, National Research Council, Washington, D.C., 1986, pp. 12-18.

Stephens, L.B., *Guardrail Warrants for Low Volume Roads*. In: Issues Surrounding Highway and Roadside Safety Management, Transportation Circular No. 416, Transportation Research Board, National Research Council, Washington, D.C., October 1993.

Ray, M. H., *The Safety Advisor: A Framework for Performing Roadside Safety Assessments.* Paper No. 940892 Transportation Research Board 73rd Annual Meeting, Washington, D.C., January 1994.

Appendix A

Cost-Effectiveness Analysis for Roadside Obstacle - Culverts

Introduction

The first column of the table indicates the speed of a vehicle in kilometers per hour (km/h). The second column of the table shows the annual cost of the guardrail including the initial cost, repair cost, and the cost of collisions with the guardrail.

The third through fifth/six columns are the cost of an accident along an unprotected section of the road. Each column represents a slightly different scenario based on type of culvert, speed, average daily traffic (ADT), culvert end height and lateral offset. If protection is recommended, the cost figure is shaded a light gray.

The chart under the table graphically illustrates the differences between alternative scenarios. If the line representing the cost of a scenario lies above the “GUARD” line, protection is recommended.

Lateral Offset

On Kansas unpaved rural roads, there is no way to describe or show a typical section of where to measure the offset from. This must be determined in the field. Depending upon local blading practices, the usable roadway width (traveled way) may vary from one local jurisdiction to another and, in fact, may vary from before and after a section is bladed. The only practical solution is for the person in charge of road and street operation and maintenance to determine and record the outer limits of the normal traveled way. This could vary from the edge of wheel paths on class C primitive (LVR Handbook) roads with two clearly defined wheel paths to the outer limits of the bladed (and usable) surface on class B or class A gravel roads. In summary, it depends upon how a gravel road surface is bladed and how it is normally driven (in relation to the usual outer limit of vehicle positioning) and field observation and judgement can only determine this.

Appendix B

Cost-Effectiveness Analysis for Roadside Obstacle - Utility Poles

Introduction

The first column of the table indicates the speed of a vehicle in kilometers per hour (km/h). The second column of the table shows the annual cost of the guardrail including the initial cost, repair cost, and the cost of collisions with the guardrail.

The third column is the cost of an accident along an unprotected section of the road. This column represents a slightly different scenario based on speed, average daily traffic (ADT) and lateral distance. If protection is recommended, the cost figure is shaded a light gray.

The chart under the table graphically illustrates the differences between alternative scenarios. If the line representing the cost of a scenario lies above the "GUARD" line, protection is recommended.

Lateral Offset

On Kansas unpaved rural roads, there is no way to describe or show a typical section of where to measure the offset from. This must be determined in the field. Depending upon local blading practices, the usable roadway width (traveled way) may vary from one local jurisdiction to another and, in fact, may vary from before and after a section is bladed. The only practical solution is for the person in charge of road and street operation and maintenance to determine and record the outer limits of the normal traveled way. This could vary from the edge of wheel paths on class C primitive (LVR Handbook) roads with two clearly defined wheel paths to the outer limits of the bladed (and usable) surface on class B or class A gravel roads. In summary, it depends upon how a gravel road surface is bladed and how it is normally driven (in relation to the usual outer limit of vehicle positioning) and this can only be determined by field observation and judgement.

Appendix C

Cost-Effectiveness Analysis for Roadside Obstacle - Embankments

Introduction

The first column of the table indicates the speed of a vehicle in kilometers per hour (km/h). The second column of the table shows the annual cost of the guardrail including the initial cost, repair cost and the cost of collisions with the guardrail.

The third through sixth/seventh columns are the costs of an accident along an unprotected section of the road. Each column represents a slightly different scenario based on speed, foreslope condition, height of fill and average daily traffic (ADT). If protection is recommended, the cost figure is shaded a light gray.

The chart under the table graphically illustrates the differences between alternative scenarios. If the time representing the cost of a scenario lies above the "GUARD" line, protection is recommended.

Lateral Offset

On Kansas unpaved rural roads, there is no way to describe or show a typical section of where to measure the offset from. This must be determined in the field. Depending upon local blading practices, the usable roadway width (traveled way) may vary from one local jurisdiction to another and, in fact, may vary from before and after a section is bladed. The only practical solution is for the person in charge of road and street operation and maintenance to determine and record the outer limits of the normal traveled way. This could vary from the edge of wheel paths on class C primitive (LVR Handbook) roads with two clearly defined wheel paths to the outer limits of the bladed (and usable) surface on class B or class A gravel roads. In summary, it depends upon how a gravel road surface is bladed and how it is normally driven (in relation to the usual outer limit of vehicle positioning) and this can only be determined by field observation and judgement.