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Guidelines for Guardrail on Low-Volume Roads

Author(s)

Eugene D. Arnold, Jr.

Performing Organization Name and Address

Virginia Transportation Research Council
Box 3817, University Station
Charlottesville, Virginia 22903-0817

Sponsoring Agencies' Names and Addresses

Va. Dept. of Transportation
1221 E. Broad Street
Richmond, Virginia 23219

University of Virginia
Charlottesville
Virginia 22903

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Abstract

Guardrail is a type of longitudinal barrier installed along a roadside to shield vehicles from hazards. Guardrail itself is a hazard and should be installed only if it would reduce the severity of accidents. Accordingly, the American Association of State Highway and Transportation Officials (AASHTO) has guidelines that can be used to evaluate the need for guardrail. The Virginia Department of Transportation (VDOT) has, for the most part, adopted these guidelines for its interstate, primary, and arterial road systems. However, these guidelines are generally based on information concerning high-speed, high-volume roads, and VDOT bases decisions regarding the need for guardrail on its secondary road system entirely on engineering judgment. Guidelines are needed to assist in evaluating the need for guardrail on secondary roads, which most typically have low-volume and low-speed traffic.

The purpose of the research was to develop such guidelines. The original scope of the study was to develop guidelines from existing practices as reported in the literature and from a survey of other states. It was concluded, however, that VDOT needed guidelines based on Virginia-specific data. Accordingly, the scope of the study was expanded to include a cost-effective analysis. Based on the application of the computer program ROADSIDE, guidelines to determine if guardrail is needed on fill embankments and for fixed objects were developed for use with secondary roads in Virginia. The former guidelines were defined in terms of volumes and fill heights for a given slope, whereas the latter guidelines were defined in terms of a required clear zone for a given volume.

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FINAL REPORT

GUIDELINES FOR GUARDRAIL ON LOW-VOLUME ROADS

E. D. Arnold, Jr.
Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Guardrail is a type of longitudinal barrier installed along a roadside to shield vehicles from hazards. Guardrail is itself a hazard and should be installed only if it would reduce the severity of accidents. Accordingly, the American Association of State Highway and Transportation Officials (AASHTO) has guidelines that can be used to evaluate the need for guardrail. The Virginia Department of Transportation (VDOT) has, for the most part, adopted these guidelines for its interstate, primary, and arterial road systems. However, these guidelines are generally based on information concerning high-speed, high-volume roads; consequently, VDOT bases decisions regarding the need for guardrail on its secondary road system entirely on engineering judgment. Guidelines are needed to assist in evaluating the need for guardrail on secondary roads, which most typically have low-volume and low-speed traffic.

The primary advantage of such guidelines is that guardrail will be more uniformly installed on low-volume roads. Final decisions regarding the use of guardrail would be dependent on sound engineering judgment; however, all decision-making would at least be based on the same methodology and analyses. Guidelines and uniform installations are of considerable benefit in deciding questions of liability. Formal guidelines should also increase the safety of the motoring public on low-volume roads. Finally, they will provide for a more cost-effective use of guardrail.

The purpose of this research was to develop such guidelines. The original scope of the study was to develop guidelines from existing practices as reported in the literature and from a survey of other states. However, it was concluded from that research that VDOT needed guidelines based on Virginia-specific data. Accordingly, the scope of the study was expanded to include the application of the computer program ROADSIDE, which was used to develop guidelines to determine whether guardrail is needed on fill embankments and for fixed objects on secondary roads in Virginia. The former guidelines were defined in terms of volumes and fill heights for a given slope, whereas the latter guidelines were defined in terms of a required clear zone for a given volume.

It is recommended that VDOT consider adopting the guidelines developed in the report to evaluate the need for guardrail on its secondary roads.

FINAL REPORT

GUIDELINES FOR GUARDRAIL ON LOW-VOLUME ROADS

E. D. Arnold, Jr.
Research Scientist

INTRODUCTION

Guardrail is a type of longitudinal barrier used to shield motorists from natural or manmade hazards located along a roadway. It may occasionally be installed to protect bystanders, pedestrians, cyclists, and property from vehicular traffic.

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). 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 guardrail. Commonly used guidelines are given in AASHTO's *Guide for Selecting, Locating, and Designing Traffic Barriers*.[1] These guidelines are incorporated into VDOT's guidelines, which are given in the Instructional & Information Memorandum entitled "Clear Zone and Traffic Barriers." [2] An updated version of the former document was published in 1989 and is entitled *Roadside Design Guide*.[3]

In VDOT's guidelines, the height and slope of the embankment are used to determine the need for guardrail on a fill section. With regard to nontraversable hazards and fixed objects, the guidelines indicate that all obstacles should be removed within certain required clear zones. The width of the clear zone is determined by the slope of the embankment (either a cut or a fill), operating speed, and volume of traffic.

These guidelines generally apply only to high-speed, high-volume roads. It is not considered cost-effective to install guardrail under these guidelines on low-volume, low-speed roads; therefore, VDOT installs guardrails on its secondary roads based on engineering judgment at the time of the field inspection and at the approaches to all bridges. There is a need for more definitive guidelines for the use of guardrail on low-volume, low-speed, rural roads.

PURPOSE AND SCOPE

The purpose of this study was to develop and recommend guidelines for use by VDOT in determining the need for guardrail on low-volume, low-speed, rural roads. Other states have such guidelines; therefore, the scope was initially limited to a review of the literature and a survey of other states. It was anticipated that existing guidelines could be adapted for use in Virginia. On completion of the state survey, however, it became apparent that VDOT needed its own Virginia-specific guidelines. Therefore, the scope was expanded to include the actual development of guidelines based on a cost-effectiveness analysis using ROADSIDE, a computer program.

METHODS

The following tasks were undertaken in this project:

1. *Review of literature.* The literature was reviewed to derive the general parameters used to determine the need for guardrail on low-volume, low-speed roads and to uncover any specific guidelines already in use. As a first step, a search of the literature was conducted through the DIALOG system available at the Virginia Transportation Research Council (VTRC). Follow-up searches of reference lists and bibliographies were conducted. Finally, contact was made with personnel in FHWA, including researchers at the Turner-Fairbank Highway Research Center, to determine their experiences with guardrail on low-volume, low-speed roads.
2. *Survey of other states.* The highway agencies in other states were contacted to determine their policies, procedures, and guidelines for installing guardrail on low-volume, low-speed roads. This was accomplished by sending a letter requesting such information to each state's representative on AASHTO's Highway Subcommittee on Design.
3. *Synthesis of findings.* Findings from the first two tasks were synthesized.
4. *Development of guidelines.* ROADSIDE, a microcomputer program described in Appendix A of AASHTO's *Roadside Design Guide*,[3] was used to analyze the cost-effectiveness of guardrail on low-volume, low-speed roads in Virginia and to develop appropriate guidelines.

RESULTS

Literature Review

AASHTO Guidelines

Since most guidelines used by other states are related to AASHTO's warrants, either directly or indirectly, it is important to define those warrants in detail.

The following information is from the *Roadside Design Guide*.[3] This document incorporates and updates information from AASHTO's barrier guide[1] and a report by the Texas Transportation Institute (TTI) in 1980.[4]

The AASHTO warrants are generally based on the idea that guardrail is needed if the consequences of striking a fixed object or running off the road would be more serious than those associated with hitting the guardrail. This method does not, however, directly consider the probability of an accident occurring or its related costs. AASHTO encourages the use of cost-benefit analysis to warrant the use of guardrail. Such analyses are "typically used to evaluate three options: (1) remove or reduce the hazard so that it no longer requires shielding, (2) install an appropriate barrier, or (3) leave the hazard unshielded." [3, p. 5-2] The third option might be applicable for low-volume, low-speed roads for which the probability of accidents is low. Chapter VII of AASHTO's barrier guide[1] presents information on such an economic analysis, and Appendix A of the *Roadside Design Guide*[3] includes a microcomputer program that updates and implements the Chapter VII procedures.

Roadside Embankments. Height of embankment and side slope are two factors that must be considered in determining the need for guardrail. Based on studies of the relative severity of encroachments on embankments versus impacts with roadside barriers, AASHTO developed the curve shown in Figure 1. Neither the probability of encroachment nor the costs were considered. Accordingly, Figures 2 and 3, developed by Georgia and North Carolina, respectively, incorporate these two factors. These figures were "presented as examples only and are not intended for direct application. Highway agencies are encouraged to develop similar warranting criteria based upon their own cost-effectiveness evaluations." [3, p. 5-2]

Roadside Obstacles. Barrier warrants for roadside obstacles are a function of the type of obstacle and the probability that it will be struck by a vehicle that has run off the road. Again, the underlying principle is that the results of striking the barrier should be less severe than those of striking the obstacle.

Hazards that normally warrant shielding are listed in Table 1. When these obstacles are immediately adjacent to the roadway, they should be either removed, relocated, modified to be less hazardous, or shielded with guardrail. As the distance between the roadway and the obstacle increases, it becomes less clear whether it is necessary to be concerned with the obstacle.

In order to determine when roadside obstacles should be of concern, the concept of a clear zone is used. *Clear zone* is defined as "the total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area." [3, p. xvii] When first introduced, it was generally accepted that the clear zone should be 30 ft. It has since been determined, however, that the clear zone is a function of traffic volume, side slope, and operating speed. Thus, based on limited empirical data, the clear-zone distance curves shown in Figure 4 were developed by AASHTO. The information in Figure 4 was tabulated by AASHTO and is shown in Table 2. The numbers from Figure 4 and Table 2

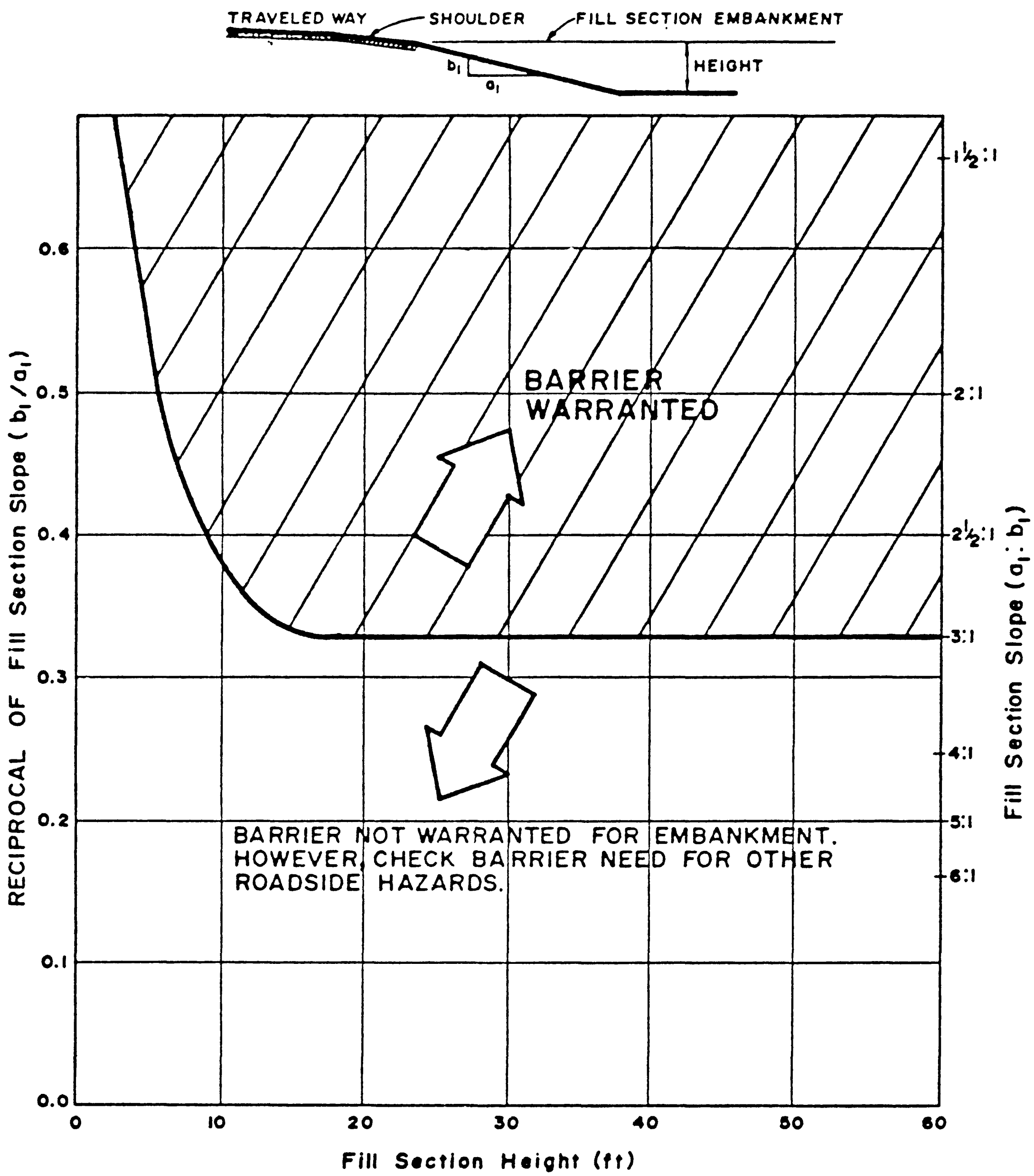

Figure 1. Comparative risk warrants for embankments. *Source*: AASHTO. 1989. *Roadside design guide.* Washington, D.C.

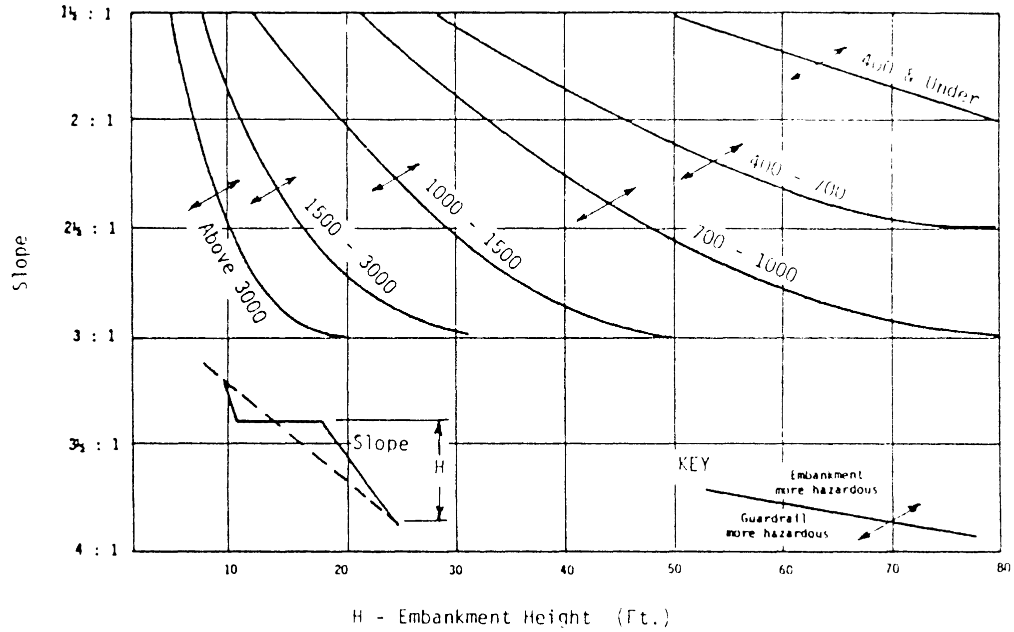

Figure 2. Example design chart for embankment warrants based on fill height and slope and on traffic volume. *Source*: AASHTO. 1989. *Roadside design guide.* Washington, D.C.

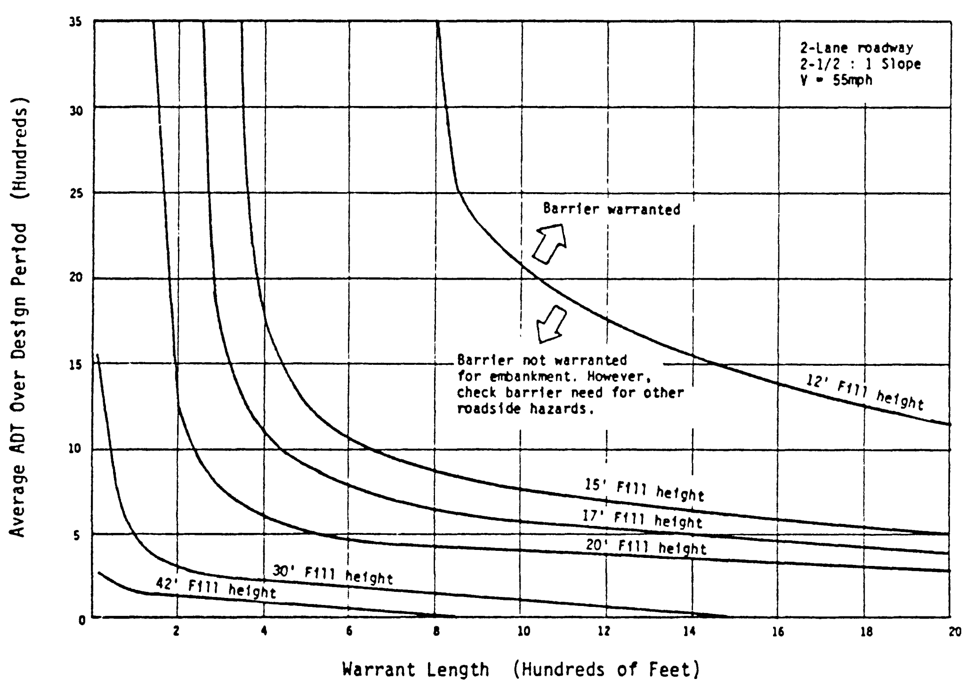

Figure 3. Example design chart for cost-effective embankment warrants based on traffic speeds and volumes, slope geometry, and length of slope. *Source*: AASHTO. 1989. *Roadside design guide.* Washington, D.C.

Table 1

Barrier Warrants for Nontraversable and Fixed Object Hazards[1,2]

bridge piers, abutments and railing ends	shielding generally required
boulders	a judgement decision based on nature of hazard and likelihood of impact
culverts, pipes, headwalls	a judgement decision based on size, shape and location of hazard
cut slopes (smooth)	shielding not generally required
cut slopes (rough)	a judgement decision based on likelihood of impact
ditches (parallel)	refer to Figures 3.6 and 3.7
ditches (transverse)	shielding generally required if likelihood of head-on impact is high
embankment	a judgement decision based on fill height and slope (see Figure 5.1)
retaining walls	a judgement decision based on relative smoothness of wall and anticipated maximum angle of impact
sign/luminaire supports[3]	shielding generally required for non-breakaway supports
traffic signal supports[4]	isolated traffic signals within clear zone on high-speed rural facilities may warrant shielding
trees	a judgement decision based on site specific circumstances
utility poles	shielding may be warranted on a case-by-case basis
permanent bodies of water	a judgement decision based on location and depth of water and likelihood of encroachment

[1]Shielding a non-traversable or fixed object hazard is usually warranted only when the hazard is within the clear zone and cannot practically or economically be removed, relocated or made breakaway, and it is determined that the barrier is a lesser hazard than the unshielded condition.
[2]Marginal situations, with respect to placement or omission of a barrier, will usually be decided by accident experience, either at the site or at a comparable site.
[3]Where feasible, all sign and luminaire supports should be a breakaway design regardless of their distance from the roadway if there is reasonable likelihood of their being hit by an errant motorist.
[4]In practice, relatively few traffic signal supports, including flashing light signals and gates used at railroad crossing, are shielded. If shielding is deemed necessary, however, crash cushions are sometimes used in lieu of a longitudinal barrier installation.

Source: AASHTO. 1989. *Roadside design guide.* Washington, D.C.

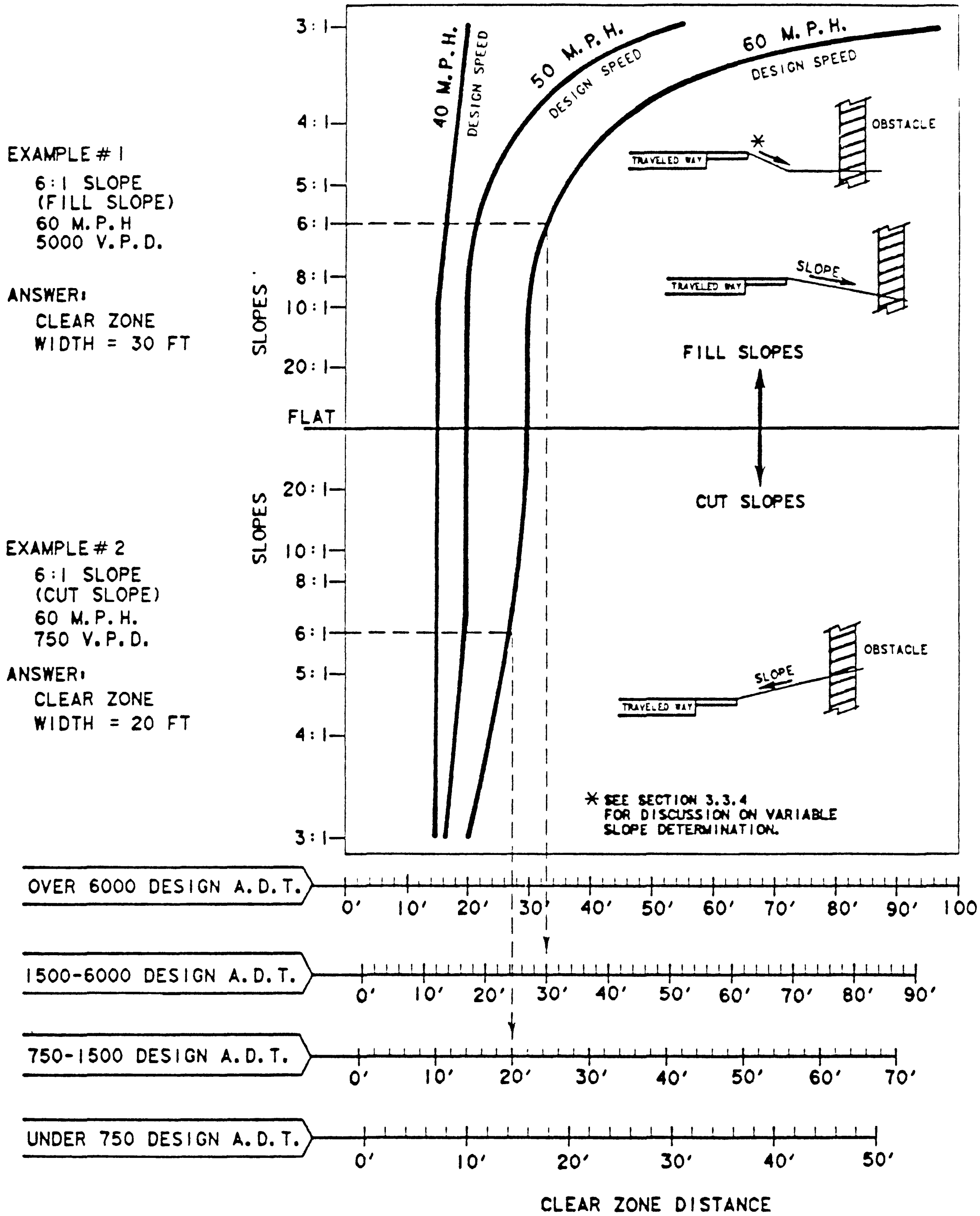

Figure 4. Clear-zone distance curves. *Source*: AASHTO. 1989. *Roadside design guide.* Washington, D.C.

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Table 2

Clear-Zone Distances (In Feet From Edge of Driving Lane)

Design Speed	Design ADT	FILL SLOPES			CUT SLOPES		
		6:1 or flatter	5:1 to 4:1	3:1	3:1	4:1 to 5:1	6:1 or flatter
40 MPH or less	Under 750	7-10	7-10	**	7-10	7-10	7-10
	750-1500	10-12	12-14	**	10-12	10-12	10-12
	1500-6000	12-14	14-16	**	12-14	12-14	12-14
	Over 6000	14-16	16-18	**	14-16	14-16	14-16
45-50 MPH	Under 750	10-12	12-14	**	8-10	8-10	10-12
	750-1500	12-14	16-20	**	10-12	12-14	14-16
	1500-6000	16-18	20-26	**	12-14	14-16	16-18
	Over 6000	18-20	24-28	**	14-16	18-20	20-22
55 MPH	Under 750	12-14	14-18	**	8-10	10-12	10-12
	750-1500	16-18	20-24	**	10-12	14-16	16-18
	1500-6000	20-22	24-30	**	14-16	16-18	20-22
	Over 6000	22-24	26-32*	**	16-18	20-22	22-24
60 MPH	Under 750	16-18	20-24	**	10-12	12-14	14-16
	750-1500	20-24	26-32*	**	12-14	16-18	20-22
	1500-6000	26-30	32-40*	**	14-18	18-22	24-26
	Over 6000	30-32*	36-44*	**	20-22	24-26	26-28
65-70 MPH	Under 750	18-20	20-26	**	10-12	14-16	14-16
	750-1500	24-26	28-36*	**	12-16	18-20	20-22
	1500-6000	28-32*	34-42*	**	16-20	22-24	26-28
	Over 6000	30-34*	38-46*	**	22-24	26-30	28-30

* Where a site specific investigation indicates a high probability of continuing accidents, or such occurrences are indicated by accident history, the designer may provide clear zone distances greater than 30 feet as indicated. Clear zones may be limited to 30 feet for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance

** Since recovery is less likely on the unshielded, traversable 3:1 slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high speed vehicles that encroach beyond the edge of shoulder may be expected to occur beyond the toe of slope. Determination of the width of the recovery area at the toe of slope should take into consideration right of way availability, environmental concerns, economic factors, safety needs, and accident histories Also, the distance between the edge of the travel lane and the beginning of the 3:1 slope should influence the recovery area provided at the toe of slope. While the application may be limited by several factors, the fill slope parameters which may enter into determining a maximum desirable recovery area are illustrated in Figure 3.2.

Source: AASHTO. 1989. *Roadside design guide.* Washington, D.C.

Table 3

Horizontal Curve Adjustments

K_{cz} (Curve Correction Factor)

DEGREE OF CURVE	DESIGN SPEED 40	45	50	55	60	65	70
2.0	1.08	1.10	1.12	1.15	1.19	1.22	1.27
2.5	1.10	1.12	1.15	1.19	1.23	1.28	1.33
3.0	1.11	1.15	1.18	1.23	1.28	1.33	1.40
3.5	1.13	1.17	1.22	1.26	1.32	1.39	1.46
4.0	1.15	1.19	1.25	1.30	1.37	1.44	
4.5	1.17	1.22	1.28	1.34	1.41	1.49	
5.0	1.19	1.24	1.31	1.37	1.46		
6.0	1.23	1.29	1.36	1.45	1.54		
7.0	1.26	1.34	1.42	1.52			
8.0	1.30	1.38	1.48				
9.0	1.34	1.43	1.53				
10.0	1.37	1.47					
15.0	1.54						

$CZ_c = (L_c)(K_{cz})$

Where: CZ_c = clear zone on outside of curvature, ft.

L_c = clear zone distance, ft., Figure 3.1 or Table 3.1

K_{cz} = curve correction factor

Note: Clear zone correction factor is applied to outside of curves only. Curves flatter than 2.0° do not require an adjusted clear zone.

Source: AASHTO. 1989. *Roadside design guide.* Washington, D.C.

"should suggest only the approximate center of a range to be considered and not a precise distance to be held as absolute." [3, p. 3-2] Finally, the clear zone may be increased on the outside of horizontal curves by applying the correction factors shown in Table 3. AASHTO indicated that "these modifications are normally only considered where accident histories indicate a need, or a specific site investigation shows a definitive accident potential which could be significantly lessened by increasing the clear zone width and such increases are cost effective." [3, p. 3-2]

In summary, if a roadside obstacle that normally warrants shielding (Table 1) is located within the clear zone (Figure 4 or Table 2 and modified per Table 3), then the obstacle should generally be removed or shielded. As indicated earlier, AASHTO suggested the use of cost-benefit analyses to determine which action to take or, in fact, whether a "do-nothing" alternative would be acceptable. Again, the do-nothing alternative would likely be applicable only for low-volume, low-speed roads.

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Current Virginia Warrants

Although VDOT guidelines for installing guardrail are presented in a different format,[2] the AASHTO warrants are used for the interstate, primary, and arterial systems. In the case of embankments, fill slopes of 3:1 or flatter do not require a barrier. On steeper slopes, fill heights more than 7.5 ft require barriers. With respect to roadside obstacles, a listing of hazards and guidelines as to whether shielding is required is given.[2] This list is comparable to that in the older AASHTO barrier guide.[1] Clear-zone requirements are based on information presented in the TTI report,[4] which, in a slightly modified form, is shown in Figure 4. Any hazard that requires shielding which is located in this clear zone must be removed or shielded. VDOT, like many other state highway agencies, is in the process of reviewing its current design practices in light of the *Roadside Design Guide*.[3]

As indicated previously, the AASHTO warrants were primarily based on high-speed, high-volume roads carrying a high functional classification. It is generally not cost-effective to install guardrail based on AASHTO standards on low-volume, low-speed roads, which are typically found on the secondary road system in Virginia. Accordingly, the practice is to install guardrail on secondary and frontage roads "at obvious needs such as bridges, large endwalls, etc., and fills where recommended during field inspection." [2, p. 9]

Survey of Other States

A letter requesting information on how their state DOT was determining the need for guardrail on low-volume roads was sent to each member of AASHTO's Highway Subcommittee on Design. A total of 39 states responded to the request. Although several states reported that they are currently reviewing or revising their guidelines, only one sent no information for that reason.

Roadside Embankments

The following are specific findings regarding guidelines or warrants for guardrail when only an embankment is being evaluated:

- Sixteen states use AASHTO warrants directly, or in a modified form, regardless of volume.
- Four states warrant guardrail based on slope only, regardless of volume:

  —*Connecticut*: steeper than 6:1

  —*Louisiana, North Dakota, and Tennessee*: steeper than 3:1.
- Three states warrant guardrail based on a height and a slope that are different from AASHTO's, regardless of volume:

Warranting Height (ft) at Slope of:

	1 1/2:1	2:1	2 1/2:1	3:1
AASHTO	3	6	9	None
Indiana	5	10	19	None
California[a]	10	12	N/A	None
Florida	All	All	All	6

[a]At locations with a high run-off-the-road accident history or potential for such accidents.

- Five states use AASHTO warrants except for low-volume or low-speed roads:

  —*Hawaii.* When speed is less than 40 mph, determine the need at field inspection.

  —*Rhode Island.* Also employ good engineering judgment and accident analysis for low-volume, rural roads.

  —*Wisconsin.* The standard practice is not to install guardrail when current ADT is less than 300.

  —*West Virginia.* Engineering judgment is used for low-volume, low-speed state projects.

  —*Kentucky.* Engineering judgment is employed at final inspection of low-volume, low-speed roads.

- Three states use the "Georgia curves" (Figure 2), which include volume as a parameter:

  —Georgia

  —Idaho

  —Texas.

- North Carolina uses its own curves (Figure 3).

- Michigan uses AASHTO warrants except for Federal-Aid Local Agency Projects, which require less conservative warrants for low-volume roads:

Warranting Height (ft)

Slope	Below 3,000 ADT	Over 3,000 ADT
2:1	Over 10	Over 5
2 1/2:1	Over 16	Over 9
3:1	Optional	Optional

- Pennsylvania uses warrants that include volume as a parameter:

Warranting Height (ft)

Slope	**>5,000**	**751–5,000**	**401–750**	**≤400**
1 1/2:1	4	6	9	17
2:1	8	10	16	31
2 1/2:1	12	16	25	49
3:1 or flatter	Guardrail not warranted			

- Colorado uses a three-step approach:

  1. Determine if guardrail is warranted based on AASHTO.
  2. If *no*, check for roadside hazards. If *yes*, guardrail is *not* required under the following slope and ADT conditions:

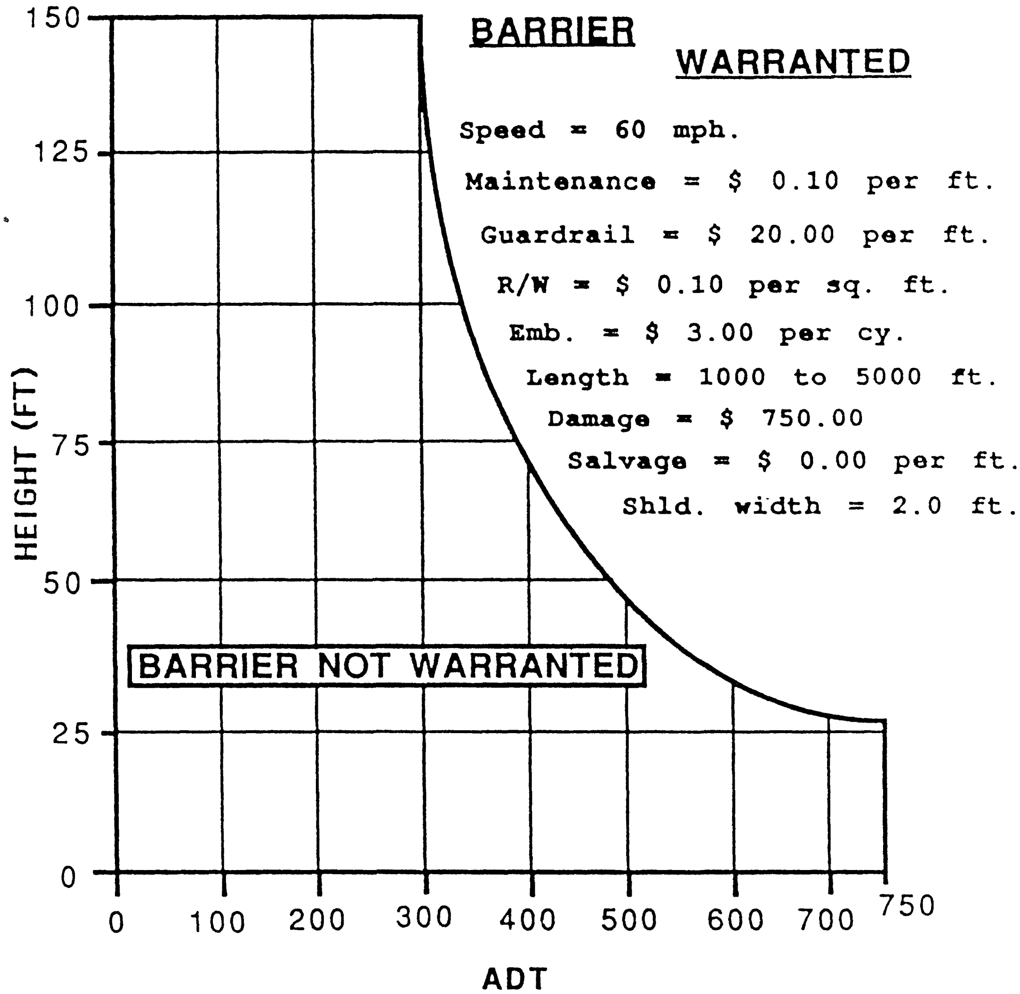
Slope	**ADT**
3:1 or flatter	Any ADT
2 1/2:1 or flatter	ADT less than 15,000
2:1 or flatter	ADT less than 7,500
1 1/2:1 or flatter	ADT less than 2,000

  3. If ADT justifies guardrail, install it. If ADT does not justify guardrail, install it only on the outside of sharp curves. (Sharp curves are those that have a design speed less than the project design speed.)

- Alaska has developed a computer program that uses a cost-effectiveness procedure to warrant all guardrail. For mid-design period ADTs less than 750, Figure 5 can be used.

- Illinois uses warrants that include volume as a parameter:

ALASKA DOT & PF PRECONSTRUCTION MANUAL
Chapter 11 - Design
July 1988 Cross Sections Sec: 11-04



EMBANKMENT BARRIER WARRANTS

ADT < 750

ADT at mid design period.

A cost effective analysis may be used to warrant barrier.

Figure 5. Embankment warrants from Alaska. *Source:* State of Alaska. Department of Transportation and Public Facilities. 1988. *Alaska DOT & PF Preconstruction Manual.* Juneau.

Warranting Height (ft)

Slope	DHV 100–200 ADT 400 & Over[a]	DHV Over 200
2:1	Over 10	Over 6
2 1/2:1	Over 20	Over 9
3:1 or flatter	No barrier system required	

[a]If ADT is less than 400, a barrier system is not required.

- Montana has a unique warranting system in which hazard values are assigned to each of six criteria at stations along the project. The need for guardrail is then based on the total of the hazard values. Guardrail is not warranted if the slope is 3:1 or flatter. Figure 6 summarizes this procedure.

Roadside Obstacles

There are two elements of the warrants or guidelines for shielding roadside obstacles that need to be addressed: the obstacle requiring guardrail and the clear-zone width.

Obstacles Requiring Guardrail. Table 4 lists all obstacles, both fixed and nontraversable objects, that were reported by at least one state as requiring guardrail. For many of the obstacles (e.g., trees and utility poles), a final treatment was left to engineering judgment in recognition of the site-specific problems often encountered in the field.

Clear-Zone Width. Twenty-seven states reported that they use AASHTO guidelines for the clear-zone width, provided information that duplicated AASHTO's guidelines, or based their guidelines on AASHTO's documents.

Twelve states reported that they basically use AASHTO's guidelines but included a statement or policy that included exceptions for low-volume or low-speed rural roads:

- West Virginia applies engineering judgment for low-volume, low-speed roads.
- Kentucky determines the need for guardrail for low-volume, low-speed roads at the field inspection.
- Texas specifies a 16-ft desirable and 10-ft minimum clear-zone width for roads with an ADT between 0 and 750.

The following Hazard Values will be used to determine embankment warrants for guardrail:

Note: Guardrail is not warranted by embankment for slopes 3:1 and flatter.

Criteria	Hazard Values
Height of fill	
Less than 3'	0
3' or Over	Height of Fill (in ft.)
Alignment	
Outside of curve	3/4 point per degree of curve
Inside of Curve	1/4 point per degree of curve
Climate	
Western Montana	10
Eastern Montana	7
Note: Multiply Hazard Value by 1.4 where roadway is shaded.	
Width of Roadway (incl. shoulders)	
20'-25'	9
26'-31'	6
32'-39'	3
Over 39'	0
4-lane Divided Highway	0

Rate of Fill Slope

ADT	1½:1	2:1	2½:1	3:1 or Flatter	
Less than 400	+35	0	*	*	
400 to 700	+22	0	-27	*	
701 to 1000	+12	0	-26	*	Use These
1001 to 1500	+ 6	0	-11	*	Hazard Values
1501 to 3000	+ 5	0	- 5	*	
Over 3000	+ 3	0	- 3	*	

*Guardrail Not Warranted by Embankment

CRITERIA	HAZARD VALUES
DOWN GRADE (PERCENT)	
0 - 3	0
4 - 6	2
7 - 10	3

THE VALUES IN THE HAZARD PROFILE COLUMNS WILL BE PLOTTED BY STATION AS SHOWN IN THE EXAMPLE WORK SHEET ON THE RIGHT.
A HORIZONTAL WARRANT LINE WILL BE ESTABLISHED ON THE PLOTTED HAZARD PROFILE BASED ON THE AVERAGE DAILY TRAFFIC (ADT) AS FOLLOWS:

ADT	WARRANT VALUE
0 - 400	100
401 - 700	65
701 - 1000	45
1001 - 1500	30
1501 - 3000	20
OVER 3000	15

Figure 6. Embankment warrants from Montana. *Source:* State of Montana. Department of Highways. 1986. *Montana Road Design Manual.* Helena.

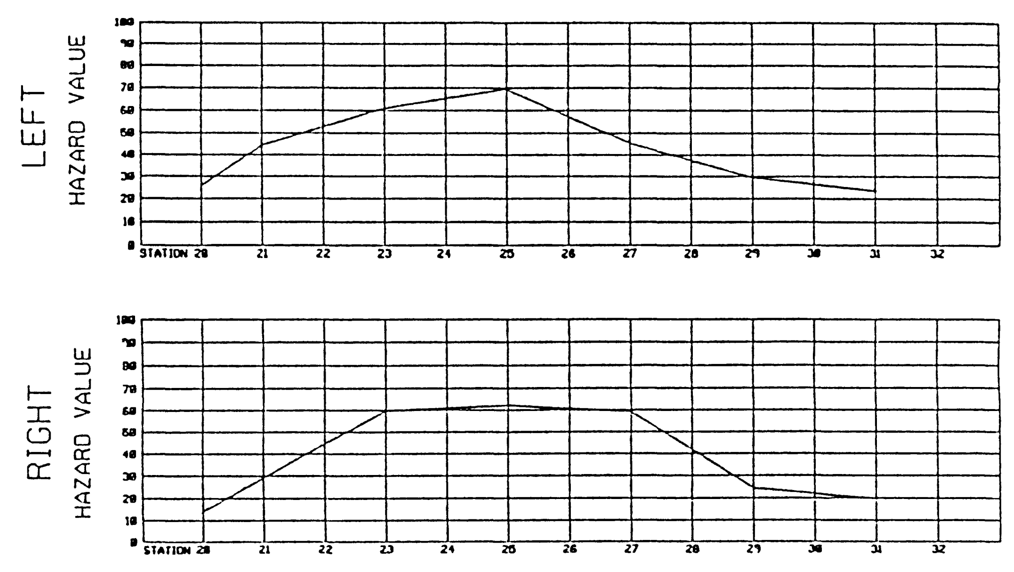
SHEET 2 OF 9

GUARDRAIL WARRANT COMPUTATION SHEET

A.D.T. 900 WARRANT VALUE 45 PROJECT NUMBER F 6-1(4)

STATION	Left: Height of Fill	Left: Rate of Fill Slope	Left: Alignment	Left: Climate	Left: Width of Roadway			Left: Down Grade	Left: Hazard Profile		Right: Height of Fill	Right: Rate of Fill Slope	Right: Alignment	Right: Climate	Right: Width of Roadway			Right: Down Grade	Right: Hazard Profile
20+00	12	0	3	10	3			0	28		3	0	1	10	3			0	17
21+00	26	0	3	10	3			0	42		16	0	1	10	3			0	30
23+00	33	12	3	10	3			0	61		35	12	1	10	3			0	61
25+00	41	12	3	10	3			0	69		38	12	1	10	3			0	64
27+00	29	0	3	10	3			0	45		32	12	1	10	3			0	58
29+00	15	0	3	10	3			0	31		14	0	1	10	3			0	28
31+00	11	0	0	10	3			0	24		7	0	0	10	3			0	70

WORK SHEET FOR DETERMINING GUARDRAIL PLACEMENT



GENERALLY, GUARDRAIL WILL BE INSTALLED ALONG THOSE SECTIONS OF THE HIGHWAY WHERE THE HAZARD PROFILE IS HIGHER THAN THE WARRANT LINE. BUT THE FOLLOWING CONSIDERATIONS SHOULD BE KEPT IN MIND:

WHERE THE HAZARD PROFILE INDICATES A NEED FOR MANY SHORT SECTIONS OF GUARDRAIL, THE DESIGNER SHOULD REALIZE THAT SUCH INSTALLATIONS WOULD BE HAZARDOUS AND IMPRACTICAL. LONG CONTINUOUS SECTIONS OF GUARDRAIL ARE PREFERABLE TO MANY SHORT SECTIONS.

Figure 6 (Continued).

Table 4

Roadside Obstacles Requiring Guardrail

Fixed Objects
Bridge piers, columns, abutments, and ends of parapets and railings
Retaining walls and culvert headwalls 4 in or more above ground
Non-breakaway supports of signs, signals, and lighting
Concrete pedestals 4 in or more above ground
Large boulders
Certain mailbox supports
Standard steel pipe with an inside diameter greater than 2 in
Concrete posts
Wood poles or posts (cross section greater than 24 to 50 sq in)
Utility poles
Barricades
Stone fences
Individual trees (greater than 4 in to 6 in in diameter)
Nontraversable Objects
Permanent bodies of water (depths greater than 2 to 4 ft)
Lines of large, nonremovable trees

- Idaho specifies a clear-zone width of 10 ft for rural roads.
- Wisconsin has the standard practice of not installing guardrail when the current ADT is less than 300.
- Rhode Island applies engineering judgment plus accident analysis for low-volume, rural roads.
- Hawaii determines the need for guardrail for low-speed roads (less than 40 mph) by the clear-zone width of 12 ft and by field inspection.
- Alaska allows a minimum clear-zone width of 7 ft for roads with an ADT less than 750 and a design speed of 40 mph or less and 10 ft with an ADT greater than 750 and a design speed of 40 mph or less.
- Ohio waives its clear-zone requirements for roads having a design speed less than 40 mph.
- Florida specifies a 14-ft desirable and 10-ft minimum clear-zone width for rural collectors with a design speed of 40 mph or less and for all rural locals.
- Illinois lists the following clear-zone widths for state-funded projects on rural highways:

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—*DHV over 200*: 23 ft

—*DHV 100–200, ADT 400–750*: 20 ft

—*ADT less than 400*: 10 ft.

- Indiana specifies a clear-zone width of 10 ft for rural collectors with a design speed of 40 mph or less and rural local roads.

Conclusions From Survey of Other States

Many states apply the AASHTO warrants regardless of volume and speed. The use of AASHTO warrants is more prevalent in the case of shielding fixed and nontraversable objects than in shielding embankments. The predominant use of AASHTO warrants can be partially attributed to the fact that in many states low-volume, low-speed roads are built and maintained by local governments, not the state highway agency.

On the other hand, many states recognize the problem of using AASHTO warrants for low-volume, low-speed roads and attempt to make allowances by reducing the requirements. The methods of reducing the warrants, however, are not consistent among the states. There are only a few states like Virginia that specify by policy that the need for guardrail be left entirely up to engineering judgment at field inspection. Most states that recognize reduced warrants for low-volume, low-speed roads provide at least minimum guidance.

The most common method of reducing warrants is through the use of cost-effectiveness analyses. Further, AASHTO recommended the use of such analyses in developing warrants and included documentation and software for such a program in Appendix A of its *Roadside Design Guide*.[3]

Cost-Effectiveness Analysis

Based on the information received from the other states and AASHTO's recommendation that states use cost-benefit analysis to warrant guardrail, the original scope of the project was expanded to include the development of Virginia-specific guidelines for embankments and for fixed objects. These guidelines were based on application of the microcomputer program ROADSIDE, which is documented in Appendix A of AASHTO's *Roadside Design Guide*.[3]

Theory and General Application of ROADSIDE

ROADSIDE allows the user to calculate the present worth and annualized cost of a specific safety improvement at a specific location. The real value of the program, however, is not in determining the absolute cost of an improvement but rather in comparing the cost of alternative improvements. It is in this context as a tool to aid designers in determining the most cost-effective solution or improvement that ROADSIDE is the most valuable and most used.

Total costs include initial construction costs, anticipated repair and maintenance costs, salvage value of the improvement, and user costs. User costs are based on the estimated number and severity of accidents associated with the particular type of improvement being evaluated. The number of accidents is based on an estimated number of encroachments and the probability that an errant vehicle will actually strike the improvement.

ROADSIDE was used in this 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, 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. Generally, guardrail was warranted if its costs were less than the do-nothing costs.

Threshold, or warranting, values were defined as points at which the cost of guardrail equaled the cost of doing nothing as certain parameters were varied in ROADSIDE. In the case of embankments, the design speed, slope, height of fill, and traffic volume were varied, and guardrail became warranted when its costs equaled the accident costs of running down the embankment. An increase in volume, 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 warranted when its costs equaled the accident costs of colliding with the fixed object. Increasing the volume 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). For a given traffic volume, an object located closer to the edge of the roadway than the threshold or warranting distance required guardrail. Thus, the warranting distance defines a clear zone in which all objects should be removed or guarded.

Procedures Used in Applying ROADSIDE

The procedures used and the assumptions made in applying ROADSIDE are most easily explained in terms of the three input screens in the program (Figures 7 through 9).

Figure 7 is the first screen in ROADSIDE and indicates the basic input data and global values used in the program. The user has the option of changing any of the 14 values shown. Figure 7 shows the values used for the guardrail analysis. Specifically, the first 7 values were changed from the default startup values. The costs associated with various accident severity levels, items 1 through 6, were derived from FHWA's Technical Advisory No. T 7570.1.[5] The values in the advisory were in 1986 dollars; therefore, they were increased to 1988 dollars based on the

```
 1. FATALITY COST         =  $  1,600,000
 2. SEVERE INJURY COST    =  $     42,000
 3. MODERATE INJURY COST  =  $     13,000
 4. SLIGHT INJURY COST    =  $      6,500
 5. PDO LEVEL 2 COST      =  $      2,200
 6. PDO LEVEL 1 COST      =  $      2,200
 7. ENCROACHMENT MODEL =  ENCRATE   * (ADTeff ^ ENC.POWER) ENCROACHMENTS/MILE/YR
                       = 0.0728500 * (ADTeff ^ 0.593500 ) ENCROACHMENTS/MILE/YR
 8. ENCROACHMENT ANGLE AT 30 MPH =    19.2 DEGREES
 9. ENCROACHMENT ANGLE AT 40 MPH =    17.2 DEGREES
10. ENCROACHMENT ANGLE AT 50 MPH =    15.2 DEGREES
11. ENCROACHMENT ANGLE AT 60 MPH =    13.0 DEGREES
12. ENCROACHMENT ANGLE AT 70 MPH =    11.6 DEGREES
13. LIMTING TRAFFIC VOLUME PER LANE =  10,000 VEHICLES PER DAY
14. SWATH WIDTH =      12 FT.

15. RESET ALL GLOBALS TO DEFAULT STARTUP VALUES.

DO YOU WISH TO CHANGE A PARAMETER VALUE (Y/N)?
```

Figure 7. ROADSIDE basic input data and global values.

```
SEVERITY INDEX versus COST RELATIONSHIP

    SEVERITY INDEX        COST
            0.0      $          0
            0.5      $      2,200
            1.0      $      2,762
            2.0      $      3,902
            3.0      $     22,306
            4.0      $     56,870
            5.0      $    139,810
            6.0      $    302,664
            7.0      $    496,934
            8.0      $    814,070
            9.0      $  1,208,470
           10.0      $  1,600,000

 PRESS ENTER TO CONTINUE
```

Figure 8. ROADSIDE severity index and accident cost relationship.

```
 1. TITLE      STARTUP VALUES
 2. TRAFFIC VOLUME =        0 VPD - TRAFFIC GROWTH = 4.0 % PER YEAR
 3. UNDIVIDED ROADWAY              1 ADJACENT LANE(S) OF  WIDTH =  9.0 FT.
 4. CURVATURE =    0.0 DEGREES        GRADE (PERCENTAGE) -    0.0
 5.               TRAFFIC   BASELINE   CURVATURE   GRADE    USER      TOTAL
                  VOLUME      ENC.      FACTOR     FACTOR   FACTOR     ENC.
    ADJACENT        0       0.0000       1.00       1.00     1.00     0.0000
    OPPOSING        0       0.0000       1.00       1.00     1.00     0.0000
 6. DESIGN SPEED =  40 MPH     ENCROACHMENT ANGLE = 17.2 DEGREES
 7. LATERAL (A) =    8     LONGITUDINAL (L) =     200     WIDTH (W) =    1 FT.
 8. INITIAL COLLISION FREQUENCY =      0.00000       IMPACTS PER YEAR
    ADJACENT     CFT= 0.0000  CF1 =  0.0000  CF2 =  0.0000  CF3 =  0.0000
    OPPOSING     CFT= 0.0000  CF4 =  0.0000  CF5 =  0.0000  CF6 =  0.0000
 9. SEVERITY INDEX =    SU= 0.00     SD= 0.00     CU= 0.00     CD= 0.00  FACE= 0.00
    ACCIDENT COST     $           0  $          0  $          0  $          0  $          0
    KT =  12.462    KJ =    0.377    CRF =    0.080    KC =   17.764
10. PROJECT LIFE = 20 YEARS    DISCOUNT RATE =   5.0 %
11. INSTALLATION COST    = $        0
12. REPAIR COST/ACC $ SU=        0  SD=       0  CU=        0  CD=        0  F=        0
13. MAINTENANCE COST/YR = $         0
14. SALVAGE VALUE       = $         0
15. PRESENT WORTH       = $         0    ANNUALIZED $         0
    HIGHWAY DEPT. COST  = $         0    ANNUALIZED $         0
 INPUT ITEM TO CHANGE  (1 TO 14) OR FUNCTION KEY PLUS ENTER
1 PRINT 2 STORE 3RECALL 4 HELP  5GLOBAL 6SI v $ 7 DIR   8SI DEF 9      10QUIT
```

Figure 9. ROADSIDE variable input data and cost calculations.

Consumer Price Index. The default encroachment model, item 7, was changed to the encroachment model in Appendix F of the Transportation Research Board's Special Report No. 214.[6]

Figure 8 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 percent chance of a fatality. Numbers within the scale represent an assumed percentage distribution among the accident severity levels shown in Figure 7. For example, accidents having an SI of 5.0 are assumed to have 0 percent property damage only (PDO), Level 1; 15 percent PDO, Level 2; 22 percent slight injury; 45 percent moderate injury; 10 percent severe injury; and 8 percent fatalities.[3, p. A-12] The accident costs in Figure 8 associated with an SI were calculated by multiplying each percentage by the cost shown in Figure 7 for each severity level and then totaling. The assumed percentage distribution for each SI is fixed within ROADSIDE and is not offered as a user option.

Figure 9 is the third screen in ROADSIDE and allows input of the variable data specific to an alternative being evaluated. The final two items show the calculated costs of the alternative. 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 was varied in both analyses, with a constant growth factor of 4.0 percent per year assumed. This factor is the average annual growth in total vehicle miles of travel on the secondary road system in Virginia between 1980 and 1987.

- *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. Geometric design standards for a rural local road system (GS-4), as defined in *Road and Bridge Standards*,[7, p. 701.04] were used to vary the lane width between 9 and 12 ft depending on the assumed traffic volume and design speed.

- *Item 4. Adjustment Factors.* ROADSIDE allows adjustment to the baseline encroachment to account for roadway curvature and grade as well as a specific user input factor for special situations. For both analyses, a value of 1.0 was used for all three factors.

- *Item 5. Traffic Volume and Encroachments.* This item is calculated in ROADSIDE by assuming splitting of the previously input traffic evenly by direction, applying the encroachment model defined earlier, and adjusting the baseline encroachment by the factors in item 4.

- *Item 6. Design Speed and Encroachment Angle.* ROADSIDE (version 4.2) allows only for design speeds of 30, 40, 50, 60, and 70 mph. Geometric design standards for a rural local road (GS-4) require design speeds ranging between 20 and 50 mph, depending on the traffic volume and terrain.[7] Because of the limitation in ROADSIDE, only three design speeds (30, 40, and 50 mph) were used in the calculations. The default encroachment angles shown in Figure 7 were used in the analysis.

- *Item 7. Hazard Definition.* In ROADSIDE, a hazard is defined with a length (L) parallel to the roadway, a width (W) generally perpendicular to the roadway, and an offset (A) from the edge of the nearest driving lane.

    In the embankment analysis, 200 ft was used for the length of both the guardrail and the embankment. Several longer lengths were tested, and 200 ft yielded the smallest height of fill at which guardrail became cost-effective. Thus this value is conservative on the side of safety. Guardrail was assigned a width of 1 ft, whereas the width of the embankment varied with the height of fill and the slope. For example, a 10-ft fill on a 2:1 slope had a 20-ft width. Likewise a 20-ft fill on the same slope had a 40-ft width. The same relation between fill height and width held for the 2 1/2:1 and the 1 1/2:1 slope (e.g., at 2 1/2:1 a 10-ft fill had a 25-ft width, and at 1 1/2:1 a 20-ft fill had a 30-ft width). The guardrail was located 3 ft from the edge of the pavement, with the embankment located at 7 ft. The offset of 3 ft is the normal guardrail location for a 2-ft shoulder width shown in Table I of the *Road and Bridge Standards*[7, p. 501.24] for traffic volumes less than 400 vehicles per day. The embankment was located at 7 ft because the maximum dynamic deflection for standard GR-2 guardrail (typically used on secondary roads) is 4 ft, as stated in the *Road and Bridge Standards*.[7, p. 501.04]

For the fixed object analysis, a 1-ft by 1-ft section of guardrail was compared with a 1-ft by 1-ft fixed object. A 1-ft length of guardrail is unrealistic; however, for analytical purposes a length of 1 ft had to be used. The probability of a vehicle striking a 175-ft length of guardrail (see following section on installation cost) in ROADSIDE is so much greater than that of striking a 1-ft-long object that guardrail is always much more expensive and therefore never warranted. The distance of the guardrail from the edge of the roadway was varied, beginning at 3 ft (from Table I referenced above). For analytical purposes, a deflection of 2 ft had to be used for placement of the guardrail in front of the fixed object; therefore, the fixed object placement began at 5 ft. Again, the probabilities in ROADSIDE of striking guardrail that is 3 to 4 ft closer to the edge of the pavement than the fixed object is so much greater that guardrail is always more expensive and therefore never warranted (except at volumes in the range of 4,000 ADT or greater).

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

- *Item 9. Severity Index.* ROADSIDE uses the SI to determine the costs of accidents. The only known data relating accidents and embankment heights and slopes were obtained in California in 1963 by Glennon and Tamburri.[8] The number of fatal, injury, and PDO accidents for given fill heights and slopes were presented for 999 accident records. For each combination of fill height and slope, an SI for this project was calculated from the formula:

$$\mathrm{SI} = \frac{12\ (\textit{Fatal Accidents}) + 3\ (\textit{Injury Accidents}) + \textit{PDO Accidents}}{\textit{Total Accidents}}$$

(VDOT's Traffic Engineering Division uses this accident weighting in calculating a severity rate.) Multiple regression analysis was then applied to the data set to establish the best-fit equation relating the dependent variable SI to the height of fill and the slope. Thus, for any given combination of slope and fill height, the SI could be calculated from the equation and then used as input to ROADSIDE. For the three slopes analyzed, the SIs ranged from 2.06 to 3.18 as the height varied from 1 to 100 ft.

Virginia accident data were available for fixed objects, including guardrail. Five years (1983–1987) of accident data categorized by severity (fatal, injury, PDO) and type (e.g., structures, guardrail, trees) on secondary roads were compiled from VDOT's annual *Summary of Accident*

Data.[9] For the embankment analysis, the formula for computing an SI was applied to the guardrail data. The computed SI of 1.97 was then used as input for ROADSIDE.

A different procedure was used in the fixed object analysis. The numbers of fatal, injury, and PDO accidents involving fixed objects on Virginia's secondary roads are known. Therefore, the actual costs of specific types of accidents can be calculated directly by applying the costs derived from the FHWA Technical Advisory.[5] ROADSIDE does not allow the user the option of directly inputting accident costs; they are calculated from an SI and the fixed SI/cost relationship built into the program. Therefore, in order to use ROADSIDE, actual costs were calculated and used in the SI/cost relationship (Figure 8) to calculate backwards to an SI. This SI was used as input for ROADSIDE so that the program would then compute the correct accident cost. This procedure was followed for accidents involving guardrail and structures. Structures were chosen because collisions in this category were the most severe of the fixed object accidents on secondary roads during the 1983–1987 analysis period. The SI used for guardrail was 3.18; the SI for structures was 3.73.

- *Item 10. Project Life and Discount Rate.* For purposes of this project, an anticipated life of 20 years and a discount rate of 5 percent were used.

- *Item 11. Installation Cost.* Based on data provided by VDOT's Construction Division for the period of July 1, 1987, to March 1, 1989, GR-2 guardrail cost $9.61/lin ft and radial GR-2 cost $12.69/lin ft. Guardrail GR-2A and radial GR-2A cost $13.59/lin ft and $18.57/lin ft, respectively. These costs were weighted by the quantity purchased during the period to determine an average cost of $10.33/lin ft. Accordingly, a cost of $10.00/lin ft was used for this project.

  For the embankment analysis, an installation cost of $2,000 was used for the guardrail (200 ft x $10). An installation cost of $2,400 was used for guardrail in the fixed object analysis. A minimum installation requires 100 ft of guardrail plus two 37.5-ft end treatments at $700 each (100 ft x $10 plus 2 x $700).

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

- *Item 13. Maintenance Cost/Year.* VDOT does not typically perform routine maintenance on guardrail; therefore, there is no cost.

- *Item 14. Salvage Value.* For purposes of this project, the salvage value of guardrail was input as $0.

- *Item 15. Present Worth/Highway Department Costs.* These are costs calculated by ROADSIDE, with highway agency costs including only items

11 through 14. Present worth is converted to an annual cost by applying the capital recovery factor.

Results of Embankment Analysis

Four parameters were varied in the embankment analysis: design speed, slope, height of fill, and 24-hr volume (ADT). Based on the GS-4 geometric standards for a rural local road,[7] fill slopes steeper than 3:1 that are likely to be encountered are 2 1/2:1, 2:1, and 1 1/2:1 (horizontal run:vertical drop). For each combination of slope and design speed, an assumed ADT was entered for ROADSIDE. The costs of the guardrail and do-nothing alternatives, using the previously described inputs, were then compared by inputting a fill height. This procedure was iteratively applied with various fill heights until the cost of the guardrail approximately equaled the cost of doing nothing. The height of fill at that point was the threshold height at which guardrail was warranted for that volume. Another volume was assumed, and the procedure again applied. This resulted in a set of data points indicating traffic volume versus threshold height of fill. The points are presented in Figures 10 through 16 for the slopes and design speeds selected. A site described by a point having a volume and height of fill falling on or to the left of the line does not require guardrail. Points to the right of the line require guardrail.

Current VDOT policy for interstate, primary, and arterial systems indicate that fill heights of 7.5 ft or less do not warrant a barrier on slopes steeper than 3:1. Therefore, all the curves developed level off at 7.5 ft in order to be consistent. The leveling may occur, however, beyond the range of ADTs shown in a particular figure.

Finally, the minimum volume in the GS-4 standards that requires a design speed of 50 mph is 400 vehicles per day.[7] At this volume, the threshold fill height was less than 7.5 ft for the 2:1 and 1 1/2:1 slopes. Therefore, in order to be consistent with current policy, secondary roads with a design speed of 50 mph and these slopes require guardrail at fill heights greater than 7.5 ft. This is noted in Figure 16.

Results of Fixed Object Analysis

Three parameters were varied in the fixed object analysis: the design speed, the offset or distance from the roadway of the fixed object, and the 24-hr volume (ADT). For each selected design speed, an assumed volume was entered in ROADSIDE. The costs of the guardrail and do-nothing alternatives, using the described input, were then compared by inputting an offset. This procedure was iteratively applied with various offsets until the cost of the guardrail approximately equaled the cost of doing nothing. The offset at that point was the threshold offset at which guardrail was warranted for that volume. Considered another way, this threshold was the nearest distance that a fixed object could be located and not require a guardrail. Thus, the threshold defined a clear zone in which any fixed objects should be removed or guarded. Another volume was assumed, and the pro-

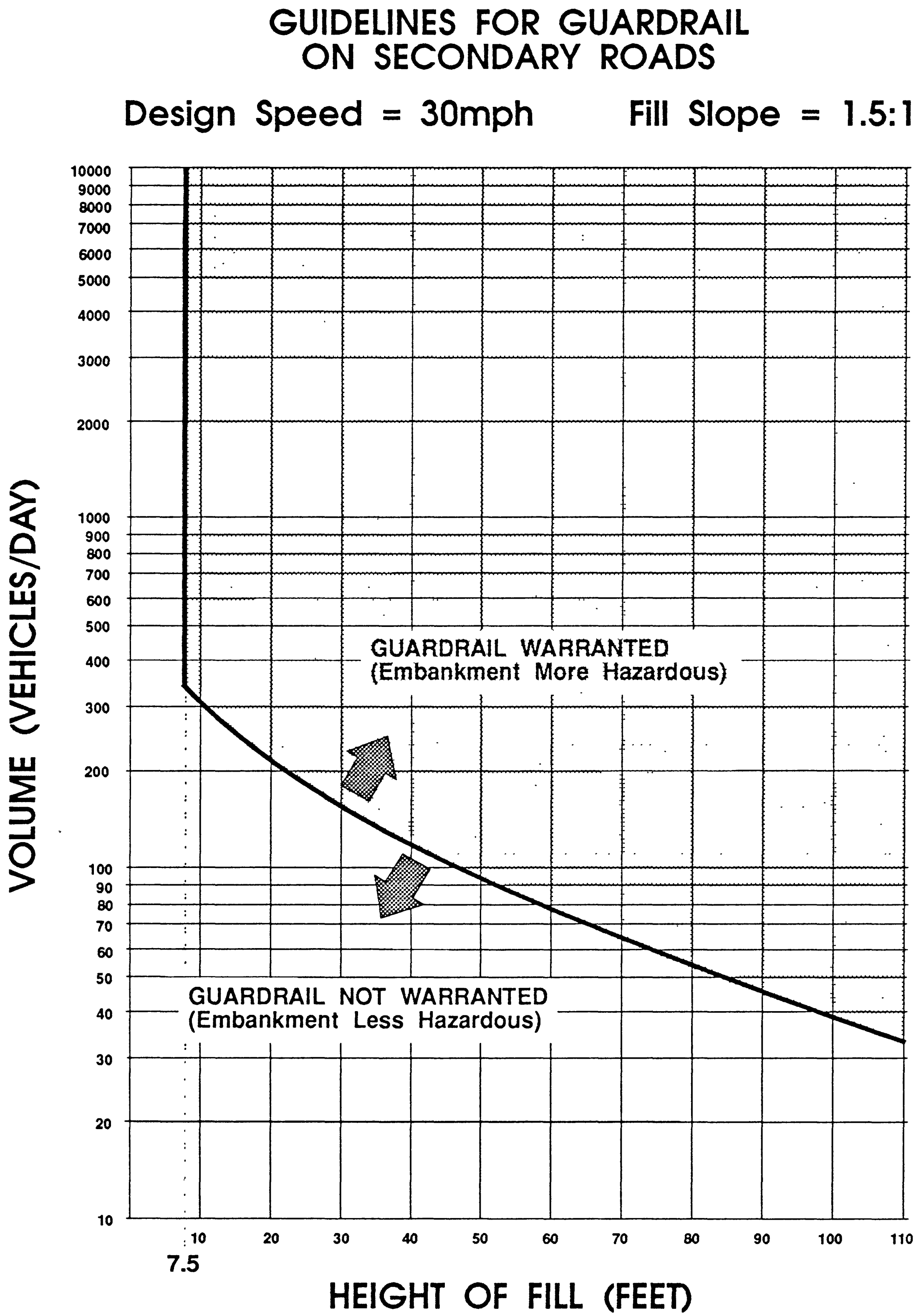


Figure 10. Guidelines for guardrail on secondary roads—30 mph design speed, 1.5:1 slope.

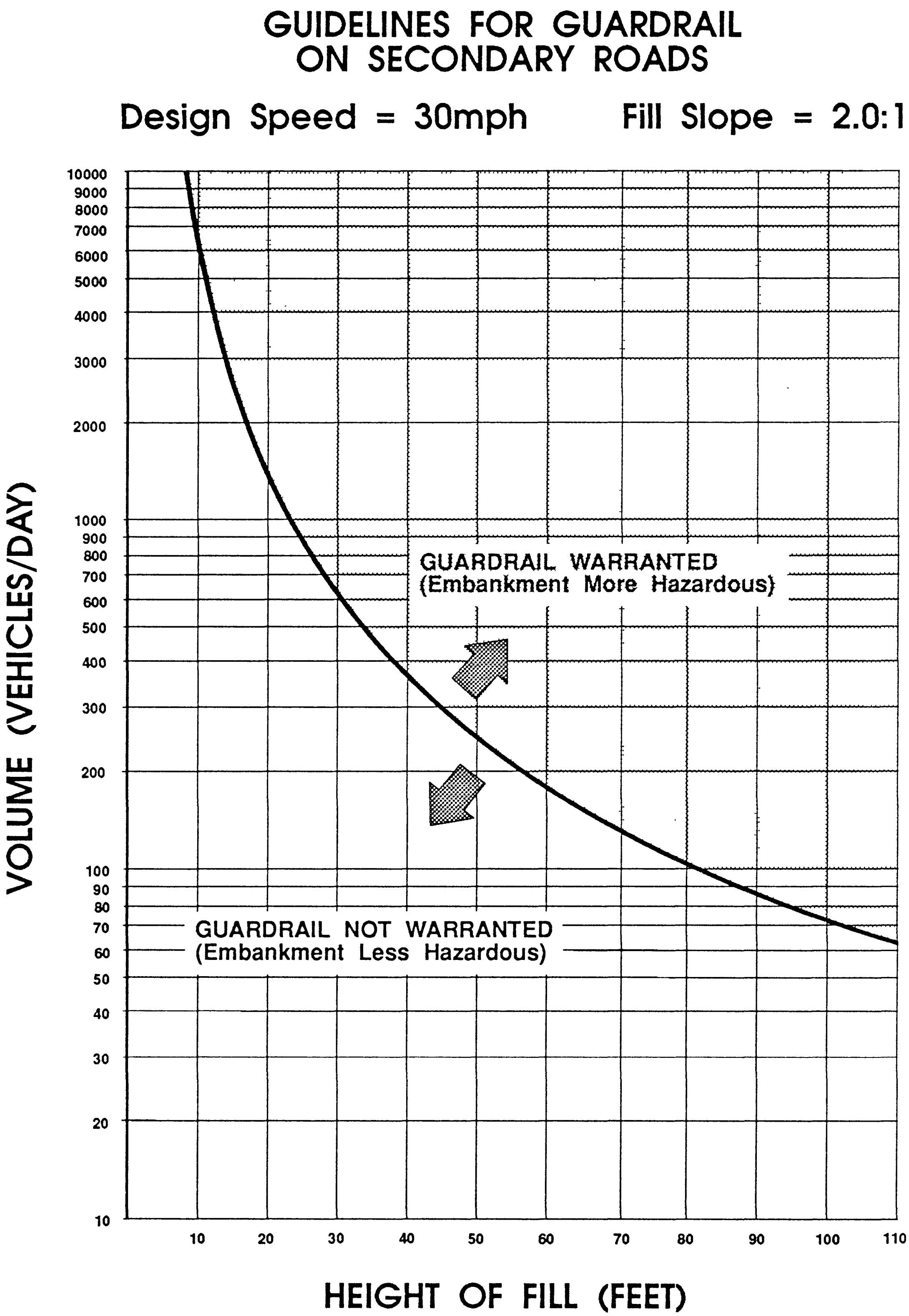


Figure 11. Guidelines for guardrail on secondary roads—30 mph design speed, 2.0:1 slope.

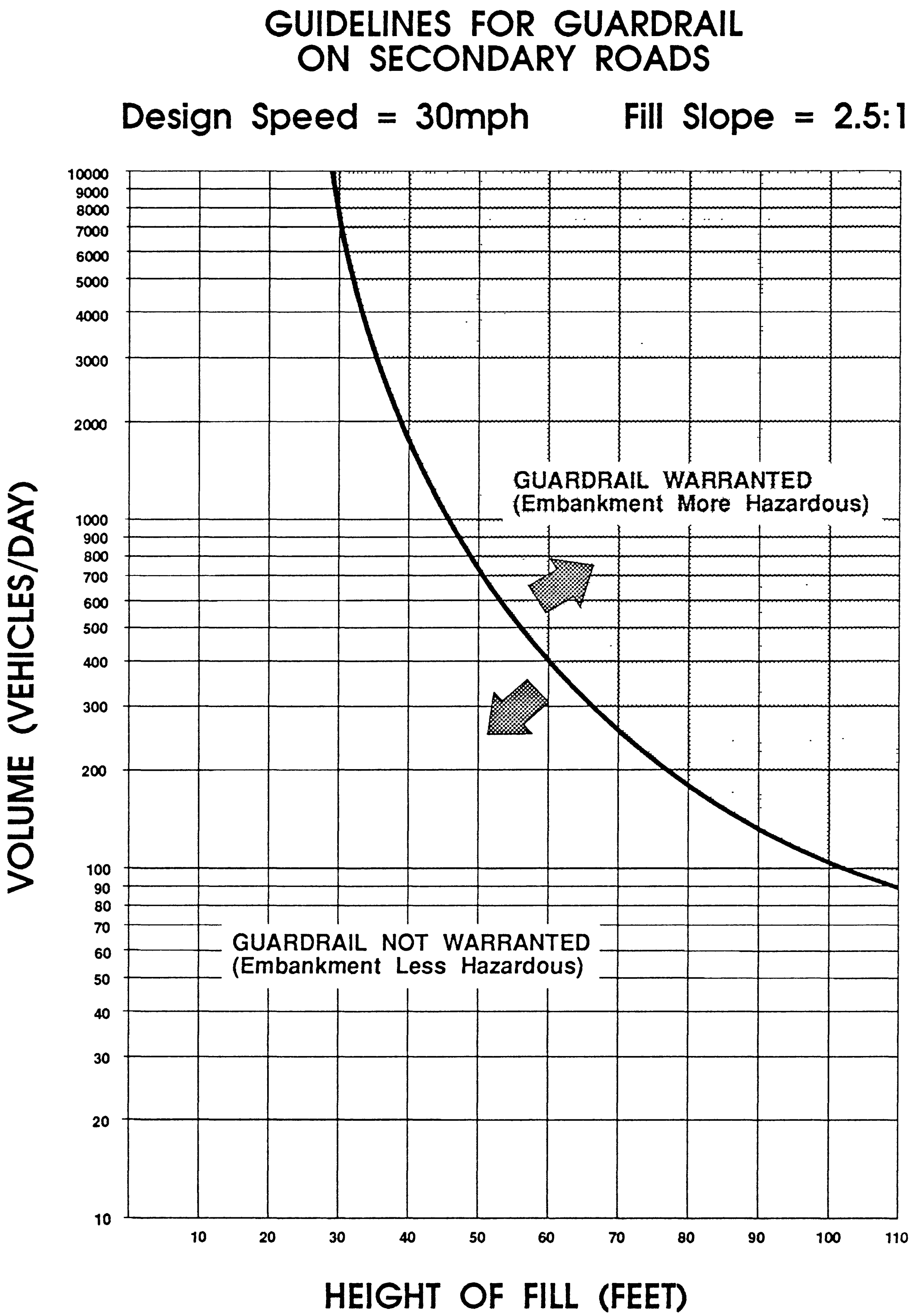


Figure 12. Guidelines for guardrail on secondary roads—30 mph design speed, 2.5:1 slope.

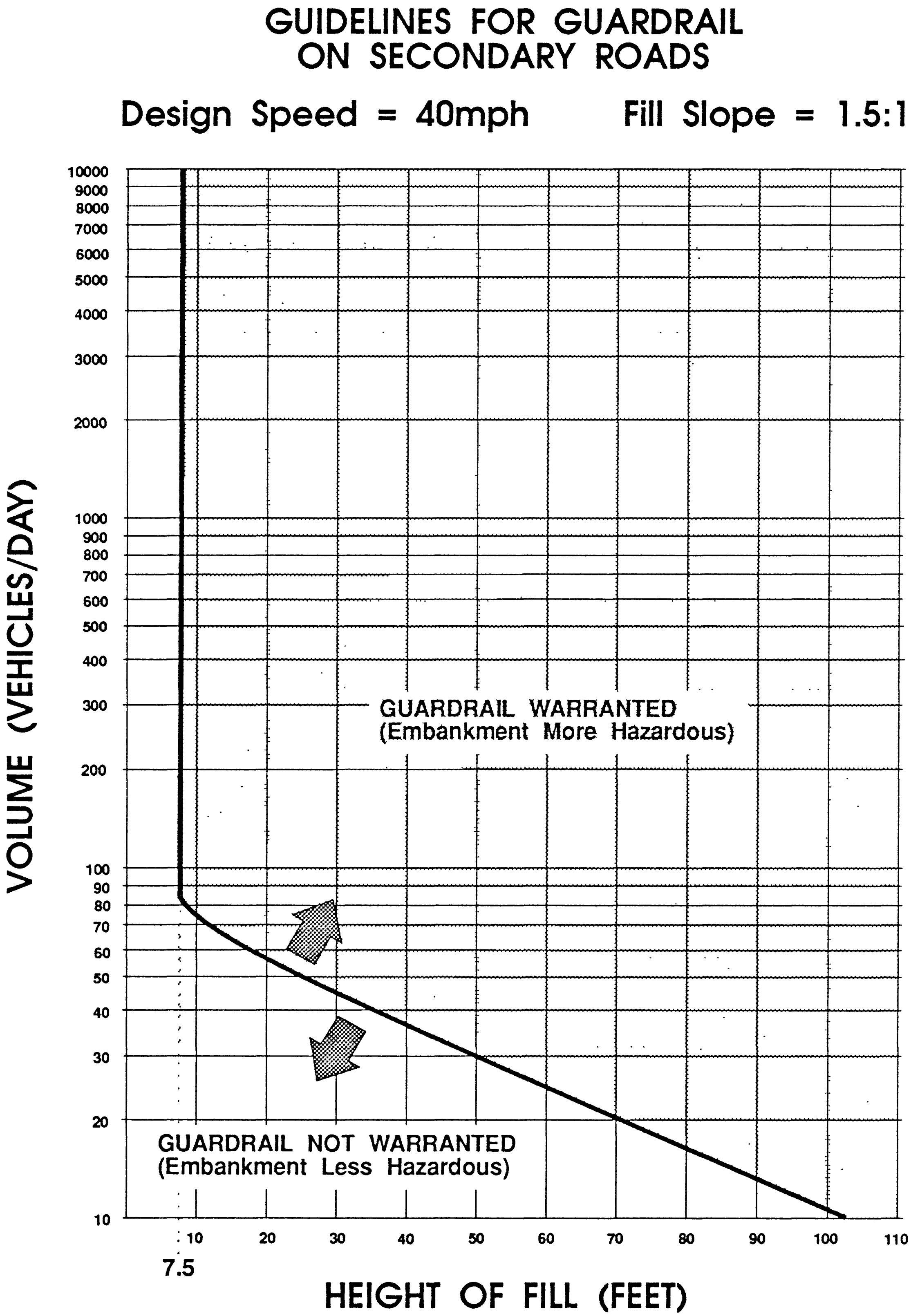


Figure 13. Guidelines for guardrail on secondary roads—40 mph design speed, 1.5:1 slope.

1530

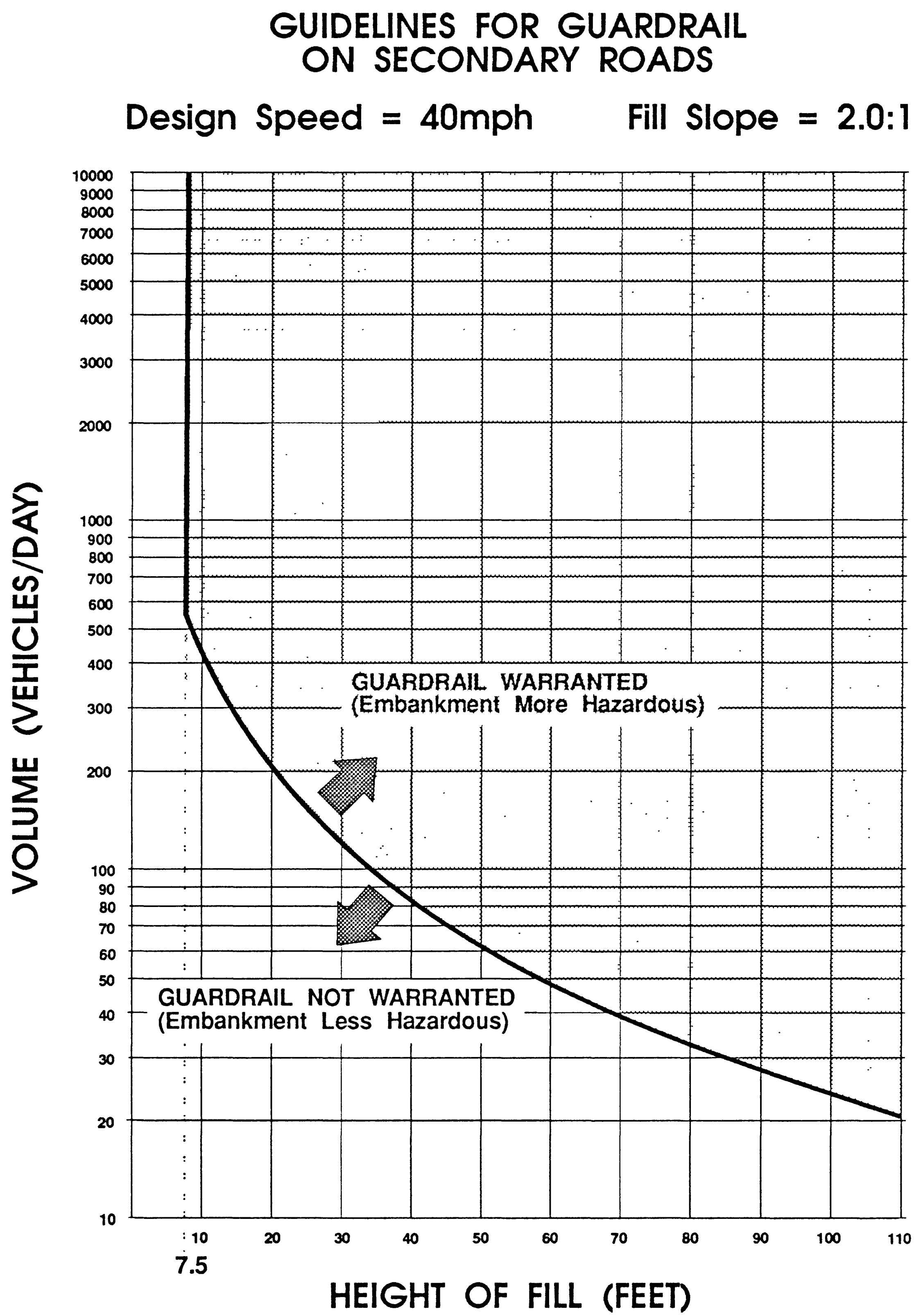


Figure 14. Guidelines for guardrail on secondary roads—40 mph design speed, 2.0:1 slope.

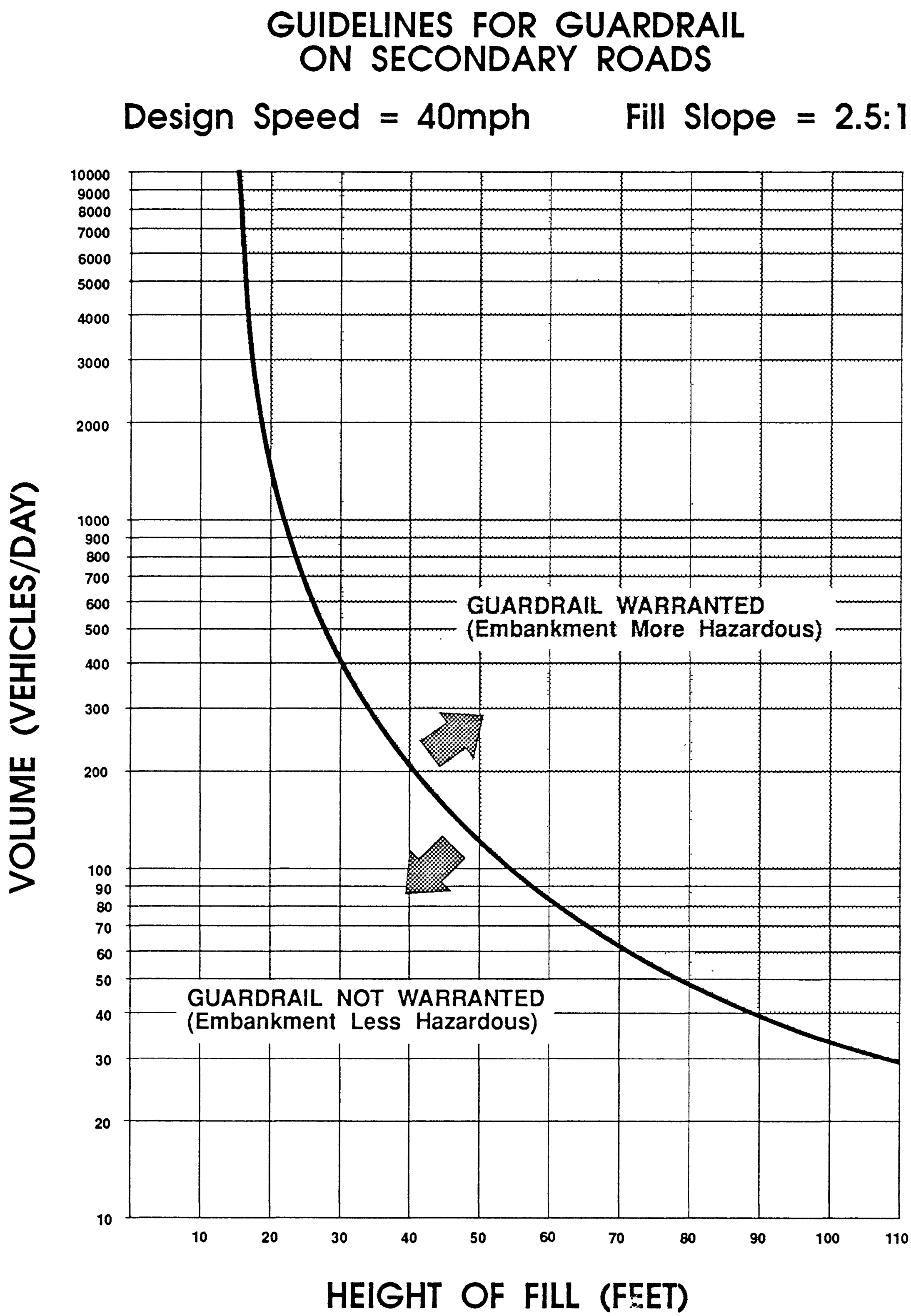
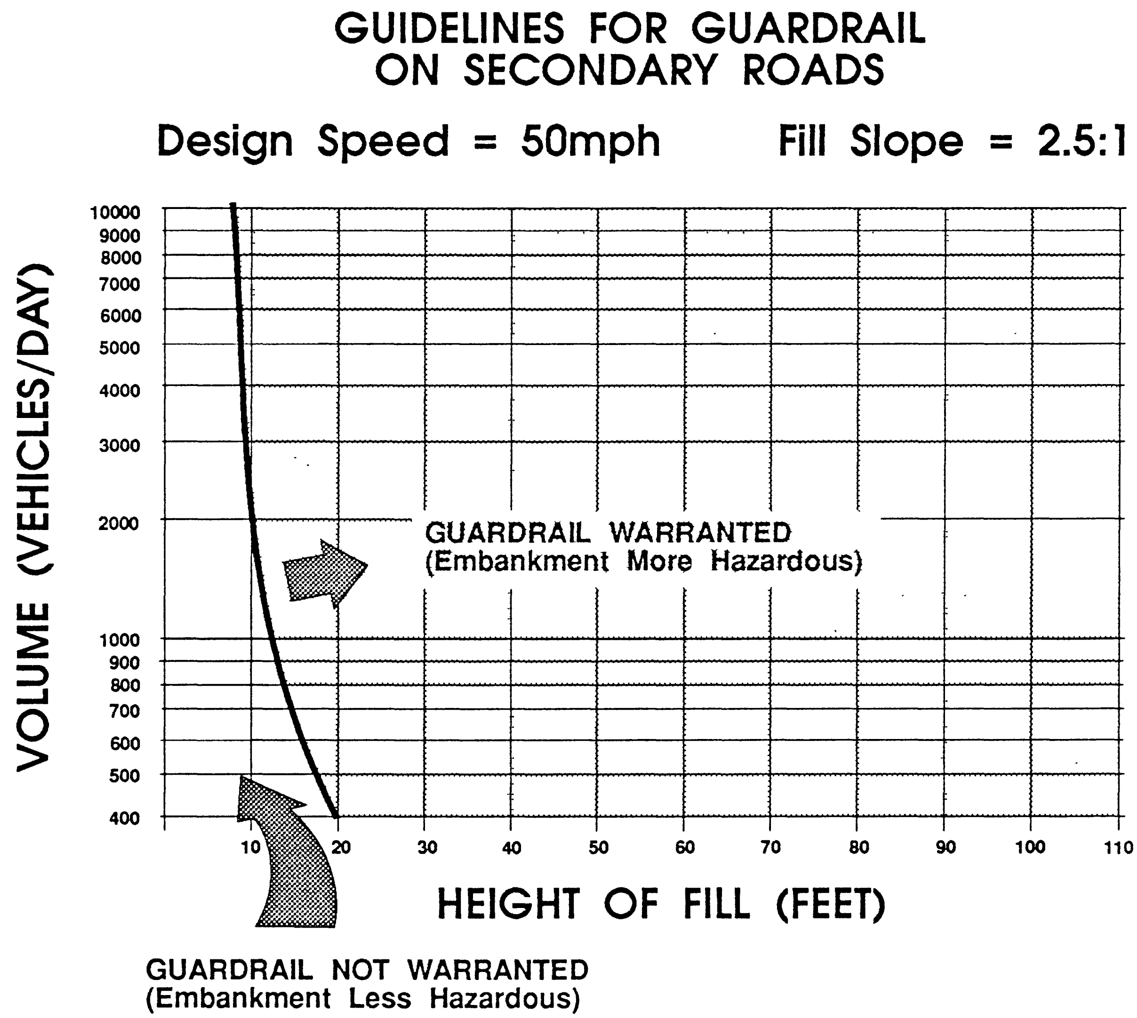


Figure 15. Guidelines for guardrail on secondary roads—40 mph design speed, 2.5:1 slope.



Note: For 2.0:1 and 1.5:1 Slopes, guardrail is warranted at fill heights > 7.5 feet.

50 mph design speed not applicable at volumes ≤ 400 vehicles/day for GS-4 standards.

Figure 16. Guidelines for guardrail on secondary roads—50 mph design speed, 2.5:1 slope.

cedure again applied. In this manner, a range of volumes requiring a given offset or clear zone was established for each design speed. The required clear zones for given volumes are presented in Table 5 for design speeds of 30, 40, and 50 mph. The minimum clear zone of 5 ft is required for ADTs less than 8,000 when the design speed is 30 mph. Since it is unlikely that volumes greater than 8,000 will be encountered at a 30-mph design speed, clear zones for ADTs beyond 8,000 were not determined.

The minimum offset or clear zone of 5 ft was assumed based on a 3-ft minimum placement of guardrail from the roadway plus a 2-ft deflection. Maximum clear zones of 10 ft for design speeds of 30 and 40 mph, and 20 ft for a design speed of 50 mph, were based on the current GS-4 design standards.[7] However, for a design speed of 50 mph and volumes greater than 1,550 vehicles per day, the clear zones required in the GS-4 standards govern for cut sections.

The fact that the GS-4 standards need to govern in cut sections is the result of a basic problem in the fixed object analysis. The method did not allow the consideration of a fixed object being located on a fill slope or cut slope. Current AASHTO guidelines (Figure 4 and Table 2) indicate that the clear zone required for a fixed

Table 5

Clear Zones for Secondary Roads

Design Speed = 50 mph		Design Speed = 40 mph		Design Speed = 30 mph	
ADT	Clear Zone (ft)	ADT	Clear Zone (ft)	ADT	Clear Zone (ft)
<475	5	<1,250	5	<8,000	5
475-525	6	1,250-1,400	6		
526-575	7	1,401-1,650	7		
576-650	8	1,651-2,050	8		
651-750	9	2,051-2,400	9		
751-850	10	>2,400	10		
851-950	11				
951-1,075	12				
1,076-1,225	13				
1,226-1,375	14				
1,376-1,550	15				
1,551-1,775	16[a]				
1,776-2,075	17[b]				
2,076-2,375	18[c]				
2,376-2,700	19[c]				
>2,700	20[c]				

[a]Except 15 ft in a cut.
[b]Except 15 ft in a cut and an ADT <2,000.
[c]Except 17 ft in a cut.

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object on a fill slope is more than that required on the same slope in a cut section. The GS-4 standards are based on AASHTO guidelines and thus also incorporate this requirement. The difference in clear zones between a fill and cut would be reflected in ROADSIDE by the cost of the accident, or the SI. The Virginia accident data used for the study did not define the roadside; therefore, it was not feasible to establish separate SIs for fill and cut sections. It is assumed, however, that the accidents occurred on a representative cross section of roadsides. Therefore, the clear zones calculated in the fixed object analysis are based on average conditions, and it is not necessary to try to distinguish between fill and cut slopes. Accordingly, the only adjustment made was to reduce the clear zones in cut sections to that required in the GS-4 standards. The clear zones developed in this study are therefore not more severe than those currently used.

CONCLUSIONS

1. *Embankments.* Secondary roads that have fill slopes steeper than 3:1 can justify not having guardrail with fill heights greater than the 7.5 ft currently required to have guardrail by VDOT on interstate, primary, and arterial roadways. The fill heights at which guardrail is required vary according to the design speed, traffic volume, and fill slope, as depicted in Figures 10 through 16.

Although vehicles may roll over on slopes steeper than 3:1, the data on which the analysis was based clearly indicate that less severe accidents occur as the slope decreases from 1 1/2:1 to 2 1/2:1.

Although ROADSIDE's output is relatively sensitive to the assumptions regarding the input parameters, the results of the analysis provide reasonable guidelines on when to install guardrail at fill embankments on secondary roads.

Because of a limitation of ROADSIDE, a 20-mph design speed could not be considered. The design speed, however, is used in ROADSIDE to determine the probability of an errant vehicle striking an object located at a given distance off the roadway. As speeds decrease, the probability of collisions decreases; therefore, the use of a 30-mph design speed in place of the 20-mph design speed overestimates the number of accidents. Thus, the use of the 30-mph curves when evaluating the need for guardrail for 20-mph design speeds results in conclusions that are conservative on the side of safety.

2. *Fixed objects.* Secondary roads can justify on a cost-effective basis clear zones less than the 10 ft currently required by VDOT's GS-4 standards. Clear zones between 5 and 10 ft vary, depending on the design speed and traffic volume, as shown in Table 5.

In order to derive realistic results, however, unrealistic assumptions had to be made to use ROADSIDE. Specifically, a 1-ft section of guardrail with only a 2-ft allowable deflection had to be used as input for ROADSIDE in order to obtain meaningful output. Further, the analysis was limited by the fact that differences between fixed objects on level and sloped roadsides could not be distinguished. Accordingly, it is not valid to change the current clear zone requirements in VDOT's GS-4 standards based on the analyses in this report.

The reduced clear zones described in this report are applicable to those limited cases where existing sites are being reviewed for guardrail need. These clear zones can be used to decide whether to shield those fixed objects currently listed in VDOT's policy.

RECOMMENDATIONS

The guidelines for guardrail developed in this study should be used by VDOT when considering the need for guardrail at specific locations on the state's secondary road system.

1. Specifically, Figures 10 through 16 should be consulted for guardrail on a fill embankment.
2. Table 5 should be consulted for fixed objects along the roadside when evaluating the need for guardrail at existing sites.
3. The clear zones in VDOT's current standards should be used for evaluating the need for guardrail on improvement projects.

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