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MISSOURI COOPERATIVE HIGHWAY RESEARCH PROGRAM

FINAL REPORT 91 – 2

GUIDELINES FOR GUARD RAIL INSTALLATION ON EMBANKMENTS AND AT BRIDGE ENDS: LOW VOLUME ROADS IN MISSOURI

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

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16. Abstract

This study evaluated the need for guard rail installation along embankments and at bridge ends on two-lane highways in Missouri. The primary objective was to identify guidelines expressed as threshold ADT values above which guard rail should be installed. Roads having an ADT of 10,000 or fewer vehicles per day and design speeds of 40, 50, and 60 mph were considered. Detailed investigations of all pertinent traffic, roadway, and cost factors were performed using the AASHTO Roadside Design Guide and the computer program known as ROADSIDE.

The results concerning guard rail along embankments indicated that guard rail was not economically justified on either 2:1 or 3:1 cross slopes if the road had a design speed of 40 mph. With a design speed of 50 or 60 mph, guard rail was found to be justified on most 2:1 cross slopes for certain combinations of ADT and embankment height. The results concerning guard rail installation at bridge ends indicated there were threshold ADT's above which guard rail should be installed at each design speed.

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GUIDELINES FOR GUARD RAIL INSTALLATION ON EMBANKMENTS AND AT BRIDGE ENDS: LOW VOLUME ROADS IN MISSOURI

Final Report

Department Study 91-2
HPR 1991-64

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December 1992

In Cooperation with the
Missouri Highway and Transportation Department
and the
U. S. Department of Transportation
Federal Highway Administration

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

EXECUTIVE SUMMARY

The Missouri Highway and Transportation Department (MHTD) currently has policies for guard rail installation along embankments on low-volume roads stating that if the average daily traffic (ADT) is under 400 vehicles per day guard rail is optional; however, good design judgment should require guard rail when conditions warrant. Guard rail will not be warranted because of embankment height for projects where clear zones are utilized, except that guard rail may be warranted as shown in Figure 5.1 of the "Roadside Design Guide" published by AASHTO in 1989. The policy also states that other factors contributing to accident severity such as hazards located either on or at the toe of the slope should be taken into consideration. The MHTD policy for installing guard rail at bridge ends specifies that it will be placed at approach ends of bridges on all roads regardless of ADT.

The current MHTD guidelines do not account for the total life cycle cost of guard rail installations; physical characteristics of the hazard such as width, length or lateral placement; the severity or costs of accidents that may occur; or the expected frequency of accident occurrence.

Therefore, detailed evaluations of all pertinent costs, encroachment rates, and severity indices were performed using the AASHTO computer program known as ROADSIDE. The primary objectives were to develop new sets of guidelines that may be used to indicate the need for guard rail installations on embankments and at bridge ends on low-volume roads. The studies were limited to two-lane two-way roadways having an ADT of 10,000 or fewer vehicles per day and design speeds of 40, 50, and 60 mph. The embankments ranged from 4 feet to 100 feet high and the cross slopes were 2:1 and 3:1.

The study results concerning guard rail installation on embankments indicated that guard rail was not necessary on either 2:1 or 3:1 cross slopes if the road had a design speed of 40 mph. However, on roads with a design speed of 50 or 60 mph, guard rail was found to be justified on most 2:1 cross slopes, but not justified on 3:1 cross slopes. Several tables and graphs were developed to illustrate the various combinations of embankment height and ADT for which guard rail should be installed on the 2:1 cross slopes.

The study results concerning guard rail installation at bridge ends indicated there were threshold ADT's above which guard rail should be installed at each of the design speeds, 40, 50, and 60 mph. A table was provided to summarize the ADT's justifying guard rail at bridge ends.

It was recommended that the guard rail installation guidelines stated in this report be adopted and implemented by MHTD at the earliest possible date.

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INTRODUCTION

The consistent and effective application of safety features along a highway is an important function of a transportation agency. Several roadside safety devices, such as guard rail and crash cushions, have proven to be highly beneficial to the motoring public when they are applied according to proper engineering principles.

The current national guidelines for selection, location and design of roadside safety devices were published by the American Association of State Highway and Transportation Officials (AASHTO) in the 1989 "Roadside Design Guide" (1). The "Roadside Design Guide" is not a standard or design policy, but, rather, it is intended to serve as a resource document from which other highway agencies can develop their standards and policies. AASHTO suggests that each agency should review the published guidelines and adjust them as may be needed to account for local conditions.

In response to the new AASHTO publication, the Missouri Highway and Transportation Department (MHTD) became interested in developing an updated and easily applied set of guidelines that could be used to determine if a guard rail installation might be economically justified in either of the two following situations:

1. At an embankment location on a two-lane low-volume roadway, with the fill cross slopes equal to 3:1 or 2:1.

2. At a bridge end location on a two-lane low-volume roadway.

Current MHTD guidelines (2) for guard rail use on high fills are:

> "Guard rail for embankments is specified on plans for roads with 400 ADT or more. For roads under 400 ADT guard rail is optional, however good design judgment should require guard rail when conditions warrant. Guard rail will not normally be warranted because of embankment height for projects where clear zones are utilized. However, guardrail may be warranted as shown on Figure 5.1 in the AASHTO Roadside Design Guide. Combinations plotting below the curve indicate conditions are less severe without guard rail. However, other factors contributing to accident severity such as hazards located either on or at the toe of the slope should be taken into consideration."

MHTD guidelines (2) for guard rail installation at bridge ends are:

> "Guard rail is placed at approach ends of bridges in accordance with typical locations shown in the standard plans for all roads. BCT sections are provided on guard rail placed for bridge end protection. Guard rail placed for bridge end protection is anchored to the bridge end

> by a bridge anchor section. ... Guard rail is not generally used to protect traffic from the ends of bridges carrying a crossroad or street over the through lanes in developed areas where speed controls exist or sidewalks are provided. If however, at ends of such bridges the roadway is in a high fill or has sharp curvature, guardrail may be considered."

Neither of the two aforementioned MHTD guidelines account for all costs pertaining to a guard rail installation, and several other factors that may affect accident experience are not considered. The frequency, severity, and current costs of accidents should be evaluated both with and without the guard rail, as well as the guard rail repair costs, the length of the roadside hazard, and other economic analysis factors such as discount rate and service life.

The necessity for performing a comprehensive evaluation of all pertinent costs associated with possible roadside safety improvements was pointed out in the 1989 AASHTO "Roadside Design Guide." A special appendix entitled 'A Cost-Effectiveness Selection Procedure' was included in that publication to assist in performing a comprehensive analysis of all traffic factors, roadway design elements, and costs involved at a site being considered for a roadside safety improvement. The numerous equations and procedures in that appendix were assembled into a computer program AASHTO has developed known as ROADSIDE. This computerized economic analysis procedure is intended to assure that guard rail 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.

The ROADSIDE computer program (Version 4.2) was utilized in this study to compare the total cost of installing guard rail to the cost of doing nothing at bridge ends or at typical embankment locations. The procedure facilitated the evaluation of a large number of conditions while allowing consideration of all pertinent costs, including the expected costs of accidents. By assuming various levels for the roadway average daily traffic (ADT), a range of conditions was identified where guard rail would be justified since its total costs were less than the do-nothing costs. These results were summarized in graphical and tabular form.

METHODOLOGY

The procedures used in this investigation were those set forth in the 1989 "Roadside Design Guide" published by AASHTO. Extensive use was made of the AASHTO computer program known as ROADSIDE, Version 4.2, which is based on an appendix entitled "A Cost-Effectivess Selection Procedure" in the "Roadside Design Guide." The ROADSIDE program was used to compare the cost of installing guard rail to the cost of doing nothing to protect an errant vehicle from possible excursion down an embankment or colliding with a bridge end.

Considering all pertinent traffic, roadway, and roadside hazard conditions, the installation of guard rail on an embankment or at a bridge end was justified if the total life cycle costs and associated accident costs were less than the costs associated with doing nothing. In the absence of guard rail, the do-nothing costs consisted of the expected annual accident costs associated with a vehicle striking the roadside hazard.

Threshold conditions, or guidelines, for using guard rail were defined as traffic levels at which the costs of installing guard rail equaled the cost of doing nothing. Once a sufficient number of the equal cost points had been determined for the specified range of average daily traffic (ADT) values, it was possible to construct a graph or table showing the roadway and traffic conditions justifying guard rail use.

ROADSIDE Program Global Parameters

Figure 1 shows the default global parameters in the ROADSIDE computer program. Items 1 through 6 are fatality, injury, and property-damage-only accident costs. The accident costs actually used in the investigation are the values shown in Figure 2. The necessary assumptions and development of the modified accident costs are described in Appendix A of this report.

Item 7 in Figure 1 is the default encroachment model, which generates the number of vehicle departures from the roadway per mile per year . The encroachment model actually used in the investigation is shown in Item 7 of Figure 2. This value was selected from an earlier study (3) which was concerned with vehicle departures from roadways in the State of Missouri.

Items 8 through 12 in Figure 1 are the encroachment angles for different design speeds and they were applied as given in ROADSIDE. Item 13, the limiting traffic volume per lane, and item 14, the swath width of an errant vehicle, were also applied as the given default values.

Input Parameters for Embankment vs. Embankment with Guardrail Analysis

The investigation of the need for guardrail at embankment locations was limited to specific low-volume roadways and design conditions of concern to the MHTD. This section summarizes the parameters that were used in the

GLOBAL PARAMETERS

1. FATALITY COST = $ 500,000
2. SEVERE INJURY COST = $ 110,000
3. MODERATE INJURY COST = $ 10,000
4. SLIGHT INJURY COST = $ 3,000
5. PDO LEVEL 2 COST = $ 2,500
6. PDO LEVEL 1 COST = $ 500

7. ENCROACHMENT RATE MODEL = 0.000500 * (ADTeff ^ 1.000000)
ENCROACHMENTS PER MILE PER YEAR

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. LIMITING TRAFFIC VOLUME PER LANE = 10,000 VEHICLES PER DAY

14. SWATH WIDTH = 12 FT.

SEVERITY INDEX	COST
0.0	$ 0
0.5	$ 500
1.0	$ 1,375
2.0	$ 3,135
3.0	$ 10,295
4.0	$ 25,350
5.0	$ 56,535
6.0	$116,555
7.0	$186,150
8.0	$281,720
9.0	$395,000
10.0	$500,000

FIGURE 1. "ROADSIDE" COMPUTER MODEL GLOBAL PARAMETERS: DEFAULT VALUES

GLOBAL PARAMETERS

1. FATALITY COST = $ 1,900,000
2. SEVERE INJURY COST = $ 419,640
3. MODERATE INJURY COST = $ 40,060
4. SLIGHT INJURY COST = $ 13,490
5. PDO LEVEL 2 COST = $ 11,590
6. PDO LEVEL 1 COST = $ 4,000

7. ENCROACHMENT RATE MODEL = 0.000742 * (ADTeff ^ 1.000000)
ENCROACHMENTS PER MILE PER YEAR

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. LIMITING TRAFFIC VOLUME PER LANE = 10,000 VEHICLES PER DAY

14. SWATH WIDTH = 12 FT.

SEVERITY INDEX	COST
0.0	$ 0
0.5	$ 4,000
1.0	$ 7,321
2.0	$ 14,001
3.0	$ 41,179
4.0	$ 98,325
5.0	$ 216,697
6.0	$ 444,521
7.0	$ 798,690
8.0	$1,071,454
9.0	$1,503,339
10.0	$1,900,000

FIGURE 2. "ROADSIDE" COMPUTER MODEL GLOBAL PARAMETERS: MODIFIED VALUES

ROADSIDE computer model when developing the guidelines for guard rail installation at embankment locations:

A. General Input Parameters:

1. Design Speed: 40, 50, and 60 mph

2. Traffic: ADT Volume Range 100 to 10,000 vehicles/day and Traffic Growth Rate equal to 3% annual growth

3. Pavement Lane Width: 11 and 12 feet

4. Lateral Placement to Obstruction: 6, 8, and 10 feet

5. Encroachment Frequency: 0.000742 x (ADT) encroachments/mile/year

6. Economic Factors: Project Life 10 years
Discount Rate 6 percent

7. Accident Costs:

Fatality	$1,900,000
Severe Injury	419,640
Moderate Injury	40,060
Slight Injury	13,490
PDO Level 2	11,590
PDO Level 1	4,000

B. Embankment Parameters:

1. Longitudinal Length: 100, 500, and 1000 feet

2. Height: 4 thru 100 feet (used to determine embankment width and value of severity indices)

3. Cross Slope: 2:1 and 3:1 (used to determine embankment width and value of severity indices)

4. Width: Variable, depending on embankment height and cross slope (subject to 120 ft maximum in ROADSIDE computer program)

5. Severity Indices (SI's):

A severity index (SI) is a number on a scale of 0 thru 10 that characterizes the severity of a collision with a roadside hazard. The SI considers the type of hazard involved and roadway design speed. The SI scale used in this investigation was consistent with the AASHTO "Roadside Design Guide." An SI equal to 0.5 represented an accident with only property damage occurring, while an SI equal to 10 corresponded to an accident with 100% chance of a fatality occurring. Intermediate SI's represented combinations of property-damage-only, injury, and fatality accidents, with the higher SI's associated with more serious accidents.

The total accident cost related to a specific SI was the product of the cost of each accident type multiplied by the probability of that accident type occurring. These probabilities are listed in the AASHTO "Roadside Design Guide." The SI's for embankment accidents used in this study were adapted from the publication "Supplemental Information for Use with the Roadside Computer Program" (4) and they are listed in Tables 1 and 2 for embankments having a 3:1 cross slope and a 2:1 cross slope.

TABLE 1.

EMBANKMENT HEIGHTS, WIDTHS, AND SEVERITY INDICES
FOR EMBANKMENTS HAVING 3:1 CROSS SLOPE

Embankment Height, (ft)	Embankment Width, (ft)	Severity Indices Design Speed (mph) 40	50	60
4	12	1.60	2.20	2.80
8	24	1.70	2.35	3.00
12	36	1.80	2.50	3.20
16	48	1.90	2.65	3.40
20	60	2.00	2.80	3.60
30	90	2.00	2.80	3.60
40	120	2.00	2.80	3.60
60	120	2.00	2.80	3.60
80	120	2.00	2.80	3.60
100	120	2.00	2.80	3.60

TABLE 2.

EMBANKMENT HEIGHTS, WIDTHS, AND SEVERITY INDICES
FOR EMBANKMENTS HAVING 2:1 CROSS SLOPE

Embankment Height, (ft)	Embankment Width, (ft)	Severity Indices Design Speed, (mph) 40	50	60
4	8	2.40	3.20	4.00
8	16	2.50	3.35	4.20
12	24	2.60	3.50	4.40
16	32	2.70	3.65	4.60
20	40	2.80	3.80	4.80
30	60	2.80	3.80	4.80
40	80	2.80	3.80	4.80
60	120	2.80	3.80	4.80
80	120	2.80	3.80	4.80
100	120	2.80	3.80	4.80

C. Guard Rail Parameters:

1. Length of Guard Rail Including Terminals: 125, 525, and 1025 feet
   These lengths of guard rail and terminal installation are required in order to protect traffic at embankments with lengths parallel to the roadway of 100, 500, and 1000 feet, respectively.

2. Width of Guard Rail at Terminal: 2 feet

3. Guard Rail Installation Costs: The total cost of installing a guard rail on an embankment was equal to the cost of the W-Beam and two Breakaway Cable Terminals (BCT's), all necessary posts and attachments, as well as the cost of additional earthwork required in order to provide a sufficient area to firmly anchor all guard rail posts. Figure 3 illustrates the dimensions pertaining to the guard rail and extra embankment cost analyses.

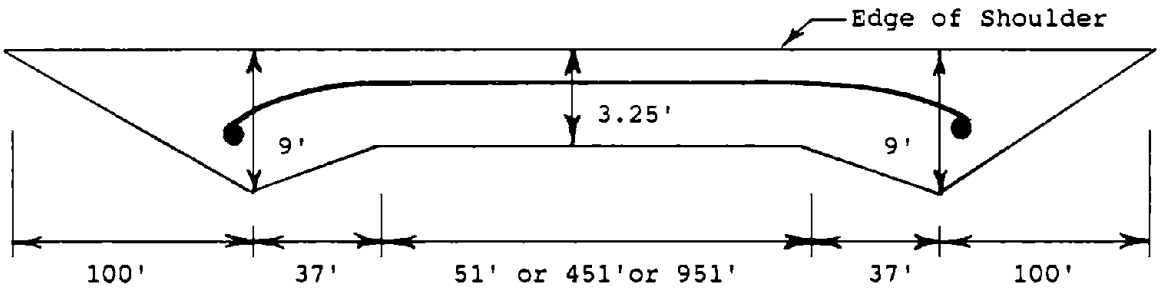


FIGURE 3. PLAN VIEW OF GUARD RAIL INSTALLATION ON AN EMBANKMENT

The installation costs for guard rail and BCT's were obtained from the MHTD in 1991. They were $700 for each BCT (two required) and $14.50 per lineal foot of Blocked-Out W-Beam. These costs are summarized in Table 3 for the lengths of guard rail and terminals being evaluated.

TABLE 3.

SUMMARY OF GUARD RAIL BLOCKED-OUT W-BEAM AND BCT COSTS

Total Length (ft)	Length of Two BCT's (ft)	BCT Costs ($)	W-Beam Length (ft)	W-Beam Cost ($)	Total Cost ($)
125	74	1,400	51	740	2,140
525	74	1,400	451	6,540	7,940
1,025	74	1,400	951	13,790	15,190

The unit cost of extra earthwork for a guard rail installation was estimated at $2.25 per cubic yard. The volume of extra earthwork was found by dividing the earthwork prism into sections and calculating the volume of each section using equations describing rectangular prisms or wedges. For guard rail and terminals having a length equal to 125 feet (100 feet of guard rail plus two crashworthy terminals at 12.5 feet each), the extra earthwork volume in cubic yards was estimated by the following equation:

$$V = \frac{(H)}{27}\left[\frac{(9+0)}{2}(100)(2) + \frac{(9+3.25)}{2}(37)(2) + (3.25)(51)\right] = 56.26(H)$$

where: V is earthwork volume in cubic yards, and
H is embankment height in feet

The initial cost of extra earthwork for a guard rail installation was then determined by specifying a value for H, the embankment height; computing the volume required; and multiplying the earthwork volume by the unit cost of $2.25 per cubic yard.

Since the service life of extra embankment was specified to be 20 years and the service life specified for the economic analysis was 10 years, a special procedure was utilized to input the cost of extra earthwork to the ROADSIDE program. The initial cost of extra embankment was converted to an equivalent annual cost by applying the uniform series capital recovery factor for 20 years and 6 percent, namely: [(A/P,6%,20) = 0.08718]. After this annual cost was computed it was placed in the ROADSIDE computer analysis as an artificial maintenance cost per year. Table 4 shows the extra embankment volumes and costs when the length of guard rail with BCT terminals was 125 feet.

TABLE 4.

EXTRA EMBANKMENT VOLUMES AND COSTS FOR LOCATIONS WITH GUARD RAIL AND TERMINAL LENGTH EQUAL TO 125 FEET

Height (ft)	Volume (cu yds)	First Cost ($)	Equivalent Uniform Annual Cost ($)
4	225.04	506	44
8	450.08	1,013	88
12	675.12	1,519	132
16	900.16	2,025	177
20	1,125.20	2,531	221
30	1,687.80	3,798	331
40	2,250.40	5,063	441
60	3,375.60	7,595	662
80	4,500.80	10,127	883
100	5,626.00	12,659	1,104

For guard rail and terminals extending for a total length of 525 feet, the extra earthwork volume in cubic yards was estimated by the following equation:

$$V = 104.41(H)$$

Table 5 shows the extra embankment volumes and costs when the total length of guard rail and terminals was 525 feet.

TABLE 5.

EXTRA EMBANKMENT VOLUMES AND COSTS FOR LOCATIONS WITH GUARD RAIL AND TERMINAL LENGTH EQUAL TO 525 FEET

Height (ft)	Volume (cu yds)	First Cost ($)	Equivalent Uniform Annual Cost ($)
4	417.64	940	82
8	835.28	1,879	164
12	1,252.92	2,819	246
16	1,670.56	3,758	328
20	2,088.20	4,698	410
30	3,132.30	7,048	614
40	4,176.40	9,397	819
60	6,264.60	14,095	1,229
80	8,352.80	18,794	1,638
100	10,441.00	23,492	2,048

For guard rail and terminals extending for a total length of 1025 feet, the extra earthwork volume in cubic yards was estimated by the following equation:

$$V = 164.59(H)$$

Table 6 shows the extra embankment volumes and costs when the total length of guard rail and terminals was 1025 feet.

D. Other Guard Rail Costs:

1. Repair Costs: W-Beam $ 250 average cost per collision
   BCT $ 600 average cost per collision

2. Maintenance Costs: W-Beam $ 0 per year
   BCT $ 0 per year

3. Salvage Value: W-Beam $ 0 at end of service life
   BCT $ 0 at end of service life

TABLE 6.

EXTRA EMBANKMENT VOLUMES AND COSTS FOR LOCATIONS WITH GUARD RAIL AND TERMINAL LENGTH EQUAL TO 1,025 FEET

Height (ft)	Volume (cu yds)	First Cost ($)	Equivalent Uniform Annual Cost ($)
4	658.36	1,481	129
8	1,316.72	2,963	258
12	1,975.08	4,444	387
16	2,633.44	5,925	517
20	3,291.80	7,407	646
30	4,937.70	11,110	969
40	6,583.60	14,813	1,291
60	9,875.40	22,220	1,937
80	13,167.20	29,626	2,583
100	16,459.00	37,033	3,229

E. Severity Indices (SI's) for Guard Rail:

SI's for guard rail were taken from the publication "Supplemental Information for use with the Roadside Computer Program" (4) and are shown below in Table 7. It was decided to use mid-range SI values for guard rail in this study since the average value would more accurately reflect the condition of the installation during its entire service life.

TABLE 7.

SEVERITY INDICES FOR ACCIDENTS INVOLVING GUARD RAIL ON EMBANKMENTS

Guard Rail Component	SI Range Speed (mph)			Average SI* Speed (mph)		
	40	50	60	40	50	60
W-Beam	2.4 to 2.8	2.8 to 3.4	3.2 to 4.0	2.6	3.1	3.6
BCT	2.4 to 3.0	2.8 to 3.6	3.4 to 4.4	2.7	3.2	3.9

* Average SI values were used in ROADSIDE computer program.

Input Parameters for Bridge End vs. Bridge End with Guard Rail Analysis

The development of guidelines for guard rail installation at bridge ends (or parapets) was limited to two-lane two-way bridges on roads with ADT ranging from 100 up to 10,000 vehicles per day. This section summarizes the parameters that were used in the ROADSIDE computer program when developing the required guidelines for guard rail installation.

A. General Input Parameters:

1. Design Speed: 40, 50, and 60 mph

2. Traffic: ADT volume range 100 to 10,000 vehicles per day and Traffic Growth Rate equal to 3 percent annual growth

3. Pavement Lane Width: 11 and 12 feet

4. Lateral Placement to Obstruction: 2, 8, and 10 feet

5. Encroachment Frequency: 0.000742 x (ADT) encroachments/mile/year

6. Economic Factors: Project Life 10 years
Discount Rate 6 percent

7. Accident Costs:

Fatality	$1,900,000
Severe Injury	419,640
Moderate Injury	40,060
Slight Injury	13,490
PDO Level 2	11,590
PDO Level 1	4,000

B. Parameters for Bridge End (Parapet) without Guardrail:

1. Longitudinal Length:

The parapet at each bridge end was assumed to be two feet long. The intervening bridge rail connecting the parapets was ignored since it was common to the analysis with or without guard rail.

2. Width:

A bridge parapet is approximately two feet wide; however, that dimension was not used for the width of hazard under the condition of not having a guard rail installed. Although it was clear that an oncoming vehicle could strike either the face or corner of a bridge parapet, it was recognized that the vehicle could entirely miss colliding with the parapet and enter the stream spanned by the bridge.

An accident involving a vehicle entering a stream usually results in severe consequences to the occupants. Furthermore, a stream constitutes a very wide lateral hazard compared to a bridge

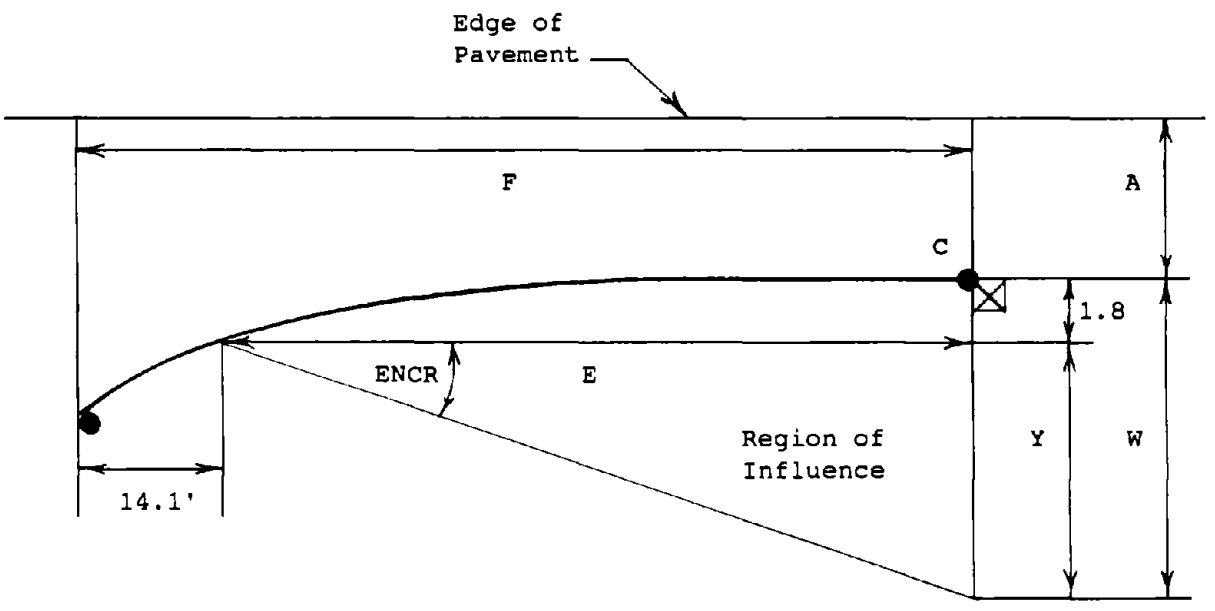
parapet. Therefore, it was decided that a stream, rather than the front of a bridge parapet, should represent the side of the roadside hazard. In order to determine the width of hazard, a reasonable estimate had to be established corresponding to the distance up or down the stream that could be reached by an errant vehicle.

To make an equitable comparison with the condition where the guard rail was installed, a "region of influence" was defined in front of the parapet where the path of an errant vehicle leaving the pavement would be affected by the guard rail if it were in place. The details of the procedure used to find the width of hazard within this "region of influence" are presented in the section of this report concerning guard rail installations at bridge ends.

An illustration of the distances and angles utilized in the width of hazard determination is shown in Figure 4. In this figure, the point labeled "C" is the inside corner of the bridge parapet and the distance labeled "A" is the lateral offset of 2, 8 or 10 feet measured from the edge of pavement. The angle "ENCR" is the encroachment angle as defined in the ROADSIDE global parameters. (Note: The guard rail is shown only for the purpose of defining the region of influence that would result if it was in place.) Other parameters are shown in Table 8.

FIGURE 4.

REGION OF INFLUENCE AT BRIDGE END AND EQUIVALENT HAZARD WIDTH THAT WOULD EXIST WITHOUT GUARD RAIL



A summary of the hazard widths with factors pertaining to the determination of the width of hazard is provided in Table 8. As can be seen in this table, the width of hazard is higher for the higher design speeds, and the width of hazard increases as the lateral offset decreases.

TABLE 8.

WIDTH OF HAZARD WITH NO GUARD RAIL INSTALLED THAT IS EQUIVALENT TO LATERAL PROTECTION OFFERED WHEN GUARD RAIL IS IN PLACE AT BRIDGE END

Design Speed (mph)	Encroachment Angle, ENCR, (degrees)	Lateral Offset, A (ft)	F (ft)	E (ft)	Y (ft)	W (ft)
40	17.2	2	57.1	43.0	13.3	15.1
		8	57.1	43.0	13.3	15.1
		10	57.1	43.0	13.3	15.1
50	15.2	2	94.6	80.5	21.9	23.6
		8	82.1	68.0	18.4	20.2
		10	69.6	55.5	15.1	16.9
60	13.0	2	169.6	155.5	35.9	37.7
		8	144.6	130.5	30.1	31.9
		10	132.1	118.0	27.3	29.0

The dimension "F" in Table 8 is the total length of anchor section, W-beam, and BCT in front of the bridge parapet.

The dimension "E" in Table 8 was found by:

$$F - 12.3 - 1.8 = E \quad \text{(in feet)}$$

The dimension "Y" in Table 8 was found by:

$$E \times \text{Tan}(ENCR) = Y \quad \text{(in feet)}$$

The dimension "W" in Table 8 was found by:

$$Y + 1.8 = W \quad \text{(in feet)}$$

3. Severity Indices (SI's) for Bridge Ends Without Guardrail

SI's for bridge ends (parapets) were estimated from those listed in the publication "Supplemental Information for Use With the

Roadside Computer Program" (4) and they are shown in Table 9.

Since the face of a bridge parapet was not specifically listed in the referenced publication, values utilized were for the face of a smooth vertical rock cut (note: identical values were listed for a W-Beam). Also, the SI's for the corner of a bridge parapet were not listed, so the values utilized were for the side of a vertical rock cut.

The SI's for the side of the hazard were assumed to be those for a permanent stream/pond with depth of water equal to 3 feet or more. It was specified by the MHTD that a "worst case" assumption should be made for bridge parapet collisions. Therefore, the highest SI value within each range of values for bridge ends was used in the ROADSIDE computer program.

TABLE 9.

SEVERITY INDICES FOR BRIDGE ENDS WITHOUT GUARD RAIL

Bridge Component	Speed (mph)	SI Range	SI Used
Face of Parapet	40	2.4 to 2.8	2.8
	50	2.8 to 3.4	3.4
	60	3.2 to 4.0	4.0
Corner of Parapet	40	4.2 to 5.0	5.0
	50	5.0 to 6.0	6.0
	60	6.0 to 7.2	7.2
Side (Permanent Stream)	40	5.0 to 6.0	6.0
	50	5.6 to 6.8	6.8
	60	6.2 to 7.6	7.6

C. Parameters for Bridge End (Parapet) with Guard Rail:

1. Length of Guard Rail (each end) for minimum installation:

BCT Terminal =	2 ft
BCT =	37 ft
Anchor Section =	18 ft
Subtotal	57 ft
Overlap onto Parapet =	2 ft
Total Length	59 ft

2. Width of Guardrail at BCT Terminal: 2 feet

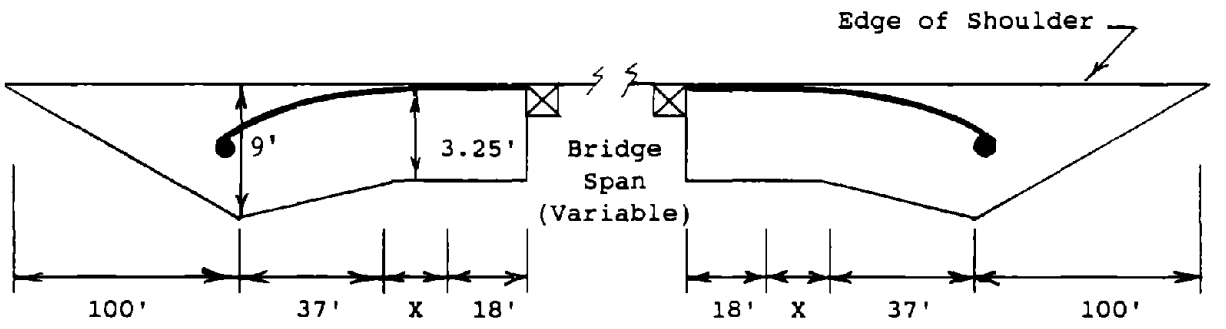
3. Guard Rail Installation Costs:

The total cost of installing a guard rail at each bridge end was equal to the cost of an anchor section, a BCT, the appropriate length of standard blocked-out W-beam sections that might be necessary, and the cost of additional earthwork that must be placed to firmly anchor all guard rail posts.

Figure 5 is a plan view showing the dimensions pertaining to the guard rail and extra embankment cost analysis. The distance labeled "X" in Figure 5 represents the variable number of feet for the blocked-out W-beam (section lengths equal to 12.5 feet each) that might be required at an installation.

FIGURE 5.

PLAN VIEW OF GUARD RAIL INSTALLATION AT BRIDGE ENDS



The costs for guard rail components at bridge ends were obtained from the MHTD in 1991 and they are shown in Table 10. As indicated previously, the total costs incurred for a specific guard rail installation depended on the number of blocked-out W-beam sections required.

TABLE 10.

BCT, W-BEAM, AND ANCHOR SECTION COSTS FOR GUARD RAIL INSTALLATION AT BRIDGE ENDS

Cost Category	Anchor Section	BCT	Blocked-Out W-Beam
First Cost, $	840 each	700 each	181.25*
Repair Cost, $	250	300	250
Maintenance Cost, $	0	0	0
Salvage Value, $	0	0	0

* Cost for one section 12.5 feet long at $14.5 per foot

On the basis of the estimates for component costs in Table 10, the total installation cost for guard rail at each end of a bridge rail could be determined by the following equation:

$$TCGR = 2(\$840 + \$700) + 2(\$181.25)(BOWB)$$

$$= \$3{,}080 + \$362.50(BOWB)$$

where: TCGR is the total installation cost of all guard rail components, and

BOWB is the number of standard 12.5 foot long sections of blocked-out W-beam guard rail required

The number of blocked-out W-beam sections required at a bridge end depended on the roadway design speed, encroachment angle, and width of hazard from which traffic should be protected. It was decided to select a "clear zone" distance for each design speed and use that value to establish a lateral distance that the guard rail would prevent a errant vehicle from encountering. Then, using the encroachment angle associated with the design speed, it was possible to determine the minimum length of guard rail that should be placed in front of the bridge end.

The extent of the clear zone selected and total length required for all guard rail components is illustrated in Figure 6, with pertinent calculations summarized in Tables 11 and 12.

FIGURE 6.

CLEAR ZONE AND LENGTH OF GUARD RAIL AT BRIDGE ENDS

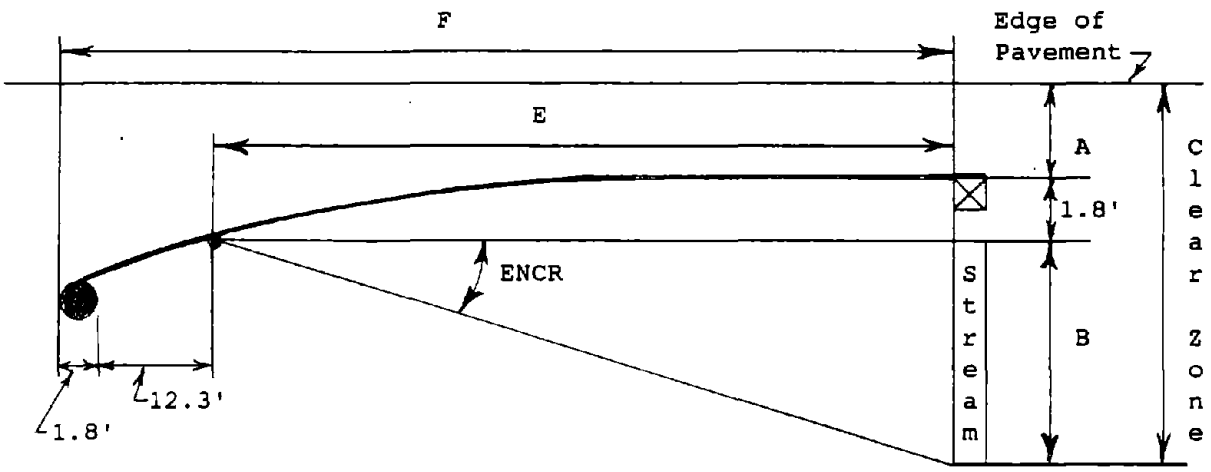


TABLE 11.

THEORETICAL AND ACTUAL LENGTH OF GUARD RAIL REQUIRED AT BRIDGE ENDS

Design Speed (mph)	Clear Zone, CZ, (ft)*	Encroachment Angle, ENCR, (degrees)	Lateral Offset A, (ft)	B (ft)	E (ft)	F (ft)	F Used (ft)
40	17	17.2	2	13.2	42.6	56.7	57.1
			8	7.2	23.2	37.3	57.1
			10	5.2	16.8	30.9	57.1
50	26	15.2	2	22.2	81.7	95.8	94.6
			8	16.2	59.6	73.7	82.1
			10	14.2	52.3	66.4	69.6
60	40	13.0	2	36.2	156.9	171.0	169.6
			8	30.2	130.8	144.9	144.6
			10	28.2	122.1	136.2	132.1

* Desired CZ from Roadside Design Guide, Table 3.1 for 4:1 cross slope.

The dimension "B" in Table 11 is found by:

Clear Zone - Lateral Offset - 1.8 = B (in feet)

The dimension "E" in Table 11 is found by:

B/(tan ENCR) = E (in feet)

The dimension "F" in Table 11 is found by:

E + 1.8 + 12.3 = F (in feet)

The total length of guard rail used in the ROADSIDE computer program depended on the standard lengths of the various components and the need to provide for protection from entering the stream as indicated by the analysis previously summarized in Table 11. These factors are all summarized in Table 12 which shows the length of each guard rail component for each combination of design speed and lateral offset.

TABLE 12.

ACTUAL LENGTH OF GUARD RAIL AND COMPONENTS REQUIRED AT BRIDGE ENDS

Design Speed (mph)	Lateral Offset A, (ft)	BCT End (ft)	BCT (ft)	BOWB* (ft)	Anchor (ft)	Sub-Total (ft)	Parapet Overlap (ft)	Total Length (ft)**
40	2	1.8	37.2	0	18.1	57.1	2	59.1
	8	1.8	37.2	0	18.1	57.1	2	59.1
	10	1.8	37.2	0	18.1	57.1	2	59.1
50	2	1.8	37.2	37.5	18.1	94.6	2	96.6
	8	1.8	37.2	25.0	18.1	82.1	2	84.1
	10	1.8	37.2	12.5	18.1	69.6	2	71.6
60	2	1.8	37.2	112.5	18.1	169.6	2	171.6
	8	1.8	37.2	87.5	18.1	144.6	2	146.6
	10	1.8	37.2	75.0	18.1	132.1	2	134.1

* Blocked-out W-Beam guard rail sections are available only in standard section lengths equal to 12.5 feet each.

** The total length values were multiplied by a factor of 2.0 prior to use in the ROADSIDE computer program.

The unit cost of extra earthwork for guard rail installation was estimated at $2.25 per cubic yard. As described in the procedures for estimating the costs of guard rail installations on embankments, the volume of additional earthwork at bridge ends was found by dividing the required earthwork prism into separate sections and calculating the volume of each section using equations for rectangular prisms or wedges.

Extra earthwork would be required both before and after each bridge parapet as illustrated in Figure 5.

Due to different requirements for the length of blocked-out W-beam guard rail sections, several equations were needed to estimate the

volume of extra embankment, as shown in the following general equation:

$$V = \frac{2H}{27}\left[\frac{(9+0)}{2}(100) + \frac{(9+3.25)}{2}(37) + (3.25)(X+18)\right]$$

where: V is earthwork volume in cubic yards,
H the embankment height in feet, and
X is the length of blocked-out W-beam needed

The initial cost of extra earthwork for a guard rail installation at a bridge end was found by assuming a value of 20 feet for H, the embankment height; computing the volume of earthwork required; and then multiplying the earthwork volume by the unit cost of $2.25 per cubic yard.

Since the service life of extra earthwork for the embankment was specified as 20 years and the service life for the overall economic analysis was 10 years, a special procedure was utilized to input the cost of extra earthwork into the ROADSIDE program. The first cost of extra embankment was converted to an equivalent annual cost by applying the uniform series capital recovery factor for 20 years and 6 percent discount rate [(A/P,6%,20) = 0.08718].

After the equivalent annual cost was computed it was entered in ROADSIDE as an artificial maintenance cost per year. Table 13 shows the extra embankment volumes and costs for several alternatives that could be assumed as being appropriate for a typical bridge end guard rail installation.

TABLE 13.

EMBANKMENT VOLUMES AND COSTS FOR GUARD RAIL INSTALLATIONS AT BRIDGE ENDS

X + 18* (ft)	Volume (cu yds)	First Cost ($)	Equivalent Uniform Annual Cost ($)
18.0	1089	2,450	214
30.5	1149	2,586	225
43.0	1209	2,721	237
55.5	1270	2,857	249
93.0	1450	3,263	284
105.5	1510	3,398	296
130.5	1631	3,669	320

* X + 18 ft is the variable dimension shown in Figure 5

4. Severity Indices (SI's) for Guard Rail Installed at Bridge Ends:

SI's for guard rail installed at bridge ends were taken from those listed in the publication "Supplemental Information for Use with the Roadside Computer Program" (4) and they are shown in Table 14. It was decided to use the mid-range SI values in this study since the average value would probably more accurately reflect the condition of the guard rail installation during its entire service life.

TABLE 14.

SEVERITY INDICES FOR GUARD RAIL AT BRIDGE ENDS

Guard Rail Component	Speed (mph)	SI Range	SI Used
Face	40	2.4 to 2.8	2.6
	50	2.8 to 3.4	3.1
	60	3.2 to 4.0	3.6
Corner and Side	40	2.4 to 3.0	2.7
	50	2.8 to 3.6	3.2
	60	3.4 to 4.4	3.9

CONCLUSIONS

Application of the ROADSIDE computer model produced valuable results that should improve the cost-effectiveness of guard rail safety projects on low volume roads. It is very important to note that the procedures and input data used in this study were based on the best accident cost, encroachment rate, and severity index information available at the time.

The future development of improved input parameters for the ROADSIDE program should be monitored to determine if a review of the findings of this study would be appropriate. This is especially important with respect to the severity indices which are still evolving. The severity indices will undoubtedly have to be adjusted in the future to reflect improved crash-worthiness of the vehicle fleet and improved performance of roadside safety devices.

Prior to a detailed presentation of the findings of this study, there will be a review of the effect of paved lane width on the ROADSIDE evaluations. Then, results concerning guard rail installation on embankments will be presented, followed by the guidelines for guard rail at bridge ends.

Embankments and Guard Rail on Embankments

1. For a design speed equal to 40 mph, guard rail installation was not found to be economically justified for any of the combinations of roadway, cross slope, or traffic conditions that were investigated.

   As shown in Tables 15, 16, and 17, for embankment heights of 4, 20, and 80 feet respectively, the total annual costs associated with guard rail installation always exceed the total annual costs for accidents on embankments without guard rail. For instance in Table 16, for an embankment height equal to 20 feet, lateral offset of 6 feet, length of obstacle equal to 500 feet, traffic volume of 10000 ADT, and lane width of 11 feet, the total annual cost on a 2:1 cross slope is $8955, on a 3:1 cross slope the cost is $3508, and the cost with guard rail installed was estimated at $9415. Since the guard rail installation yielded the highest total annual cost, it is not the preferred alternative for the given set of conditions.

   Engineering judgment should be carefully applied in evaluating an actual embankment situation where guard rail has not been proven to be the most cost-effective alternative in this study. In particular, if there is any unusual aspect of the roadside that might constitute a more severe hazard than the embankment itself, the ROADSIDE program should be applied to evaluate the effects of that hazard.

   It may also be noted in Tables 15, 16, and 17 that the total annual costs are not substantially different for the two different paved lane widths (11 and 12 feet) that were evaluated. These three tables do clearly show the manner in which total annual costs increase with increases in ADT, as well as with increases in the length of the roadside hazard.

TABLE 15.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 40 MPH DESIGN SPEED, 11 FT AND 12 FT DRIVING LANE WIDTHS, AND 4 FT EMBANKMENT HEIGHT

EMB or GR **	Lateral Offset, A, (ft)	Length of Obstacle, L, (ft)	Total Annual Cost ($) for Alternative* 1000 ADT Lane Width (ft) 11	12	10000 ADT Lane Width (ft) 11	12
2:1	6	100	153	149	1529	1493
3:1	6	100	71	69	705	689
GR	6	125	556	551	2550	2498
2:1	8	100	125	122	1248	1218
3:1	8	100	58	56	576	562
GR	8	125	516	511	2142	2098
2:1	10	100	102	100	1024	999
3:1	10	100	47	46	472	461
GR	10	125	483	479	1818	1781
2:1	6	500	618	603	6178	6031
3:1	6	500	282	276	2823	2756
GR	6	525	1953	1935	9087	8899
2:1	8	500	503	491	5034	4911
3:1	8	500	230	224	2300	2244
GR	8	525	1807	1791	7619	7462
2:1	10	500	413	403	4127	4025
3:1	10	500	189	184	1885	1839
GR	10	525	1690	1677	6455	6326
2:1	6	1000	1199	1170	11998	11703
3:1	6	1000	547	534	5469	5339
GR	6	1025	3699	3664	17258	16900
2:1	8	1000	977	953	9756	9528
3:1	8	1000	446	435	4455	4347
GR	8	1025	3420	3390	14465	14167
2:1	10	1000	800	781	8005	7808
3:1	10	1000	365	356	3652	3562
GR	10	1025	3199	3174	12252	12005

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment, stated as cross slope. GR = Guard rail.

TABLE 16.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 40 MPH DESIGN SPEED, 11 FT AND 12 FT DRIVING LANE WIDTHS, AND 20 FT EMBANKMENT HEIGHT

EMB or GR **	Lateral Offset, A, (ft)	Length of Obstacle, L, (ft)	Total Annual Cost ($) for Alternative* 1000 ADT Lane Width (ft) 11	1000 ADT Lane Width (ft) 12	10000 ADT Lane Width (ft) 11	10000 ADT Lane Width (ft) 12
2:1	6	100	227	215	2274	2145
3:1	6	100	89	85	891	851
GR	6	125	733	728	2727	2675
2:1	8	100	186	176	1855	1750
3:1	8	100	73	69	727	694
GR	8	125	693	688	2319	2275
2:1	10	100	152	144	1521	1436
3:1	10	100	60	57	596	569
GR	10	125	660	656	1995	1958
2:1	6	500	895	867	8955	8667
3:1	6	500	351	341	3508	3405
GR	6	525	2281	2263	9415	9227
2:1	8	500	730	706	7296	7058
3:1	8	500	286	277	2342	2273
GR	8	525	2135	2119	7947	7790
2:1	10	500	598	579	5980	5785
3:1	10	500	234	227	2342	2273
GR	10	525	2018	2005	6783	6654
2:1	6	1000	1731	1682	17305	16818
3:1	6	1000	678	660	6779	6598
GR	6	1025	4216	4181	17775	17417
2:1	8	1000	1410	1369	14096	13693
3:1	8	1000	552	537	5522	5372
GR	8	1025	3937	3907	14982	14684
2:1	10	1000	1155	1122	11553	11221
3:1	10	1000	453	440	4525	4402
GR	10	1025	3716	3691	12769	12522

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment, stated as cross slope. GR = Guard Rail.

TABLE 17.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 40 MPH DESIGN SPEED, 11 FT AND 12 FT DRIVING LANE WIDTHS, AND 80 FT EMBANKMENT HEIGHT

EMB or GR **	Lateral Offset, A, (ft)	Length of Obstacle, L, (ft)	Total Annual Cost ($) for Alternative* 1000 ADT Lane Width (ft) 11	1000 ADT Lane Width (ft) 12	10000 ADT Lane Width (ft) 11	10000 ADT Lane Width (ft) 12
2:1	6	100	227	215	2274	2145
3:1	6	100	89	85	891	851
GR	6	125	1395	1390	3389	3337
2:1	8	100	186	176	1855	1750
3:1	8	100	73	69	727	694
GR	8	125	1355	1350	2978	2937
2:1	10	100	152	144	1521	1436
3:1	10	100	60	57	596	569
GR	10	125	1322	1318	2657	2620
2:1	6	500	895	867	8955	8667
3:1	6	500	351	341	3508	3405
GR	6	525	3509	3491	10643	10455
2:1	8	500	730	706	7296	7058
3:1	8	500	286	277	2342	2273
GR	8	525	3363	3347	9175	9018
2:1	10	500	598	579	5980	5785
3:1	10	500	234	227	2342	2273
GR	10	525	3246	3233	8011	7882
2:1	6	1000	1731	1682	17305	16818
3:1	6	1000	678	660	6779	6598
GR	6	1025	6153	6118	19712	19354
2:1	8	1000	1410	1369	14096	13693
3:1	8	1000	552	537	5522	5372
GR	8	1025	5874	5844	16919	16621
2:1	10	1000	1155	1122	11553	11221
3:1	10	1000	453	440	4525	4402
GR	10	1025	5653	5628	14706	14459

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment, stated as cross slope. GR = Guard rail.

2. Prior to completing a detailed analysis for design speeds of 50 mph and 60 mph, it was decided to evaluate the need for running the ROADSIDE computer program using paved lane widths of both 11 feet and 12 feet. Experience with the 40 mph analyses indicated very little difference existed in the total annual cost for these two paved lane widths.

   As was anticipated, the threshold ADT's for the installation of guard rail were very close to each other for the two pavement widths. This is clearly shown in Table 18. For instance, assuming a design speed of 60 mph and a length of embankment of 500 feet, the threshold ADT for guard rail on a lane 11 feet wide is 308 vehicles per day, and on a lane 12 feet wide it is 314 vehicles per day. Such a small difference in ADT would be difficult to estimate for any low-volume roadway.

   Since the differences in results attributable to width of paved lane were so small, it was decided that all remaining analyses and study conclusions would be based on the 11 foot wide paved lane input to the ROADSIDE computer program.

TABLE 18.

COMPARISON OF ADT GUIDELINES FOR GUARD RAIL INSTALLATION ON EMBANKMENTS WITH DRIVING LANE WIDTHS EQUAL TO 11 FT AND 12 FT

Design Speed, (mph)	Lane Width, (ft)	ADT Guideline for Guard Rail Installation* Length of Guard Rail (ft)		
		100	500	1000
50	11	1537	1144	1079
	12	1571	1171	1103
60	11	356	308	299
	12	363	314	305

* Break-even ADT for 2:1 cross slope, embankment height 20 feet, and lateral offset equal to 6 feet. Roads with traffic exceeding the listed ADT values should have guard rail installed.

3. For a design speed of 50 mph, guard rail installation was found to be economically justified for numerous traffic and roadway situations where the embankment cross slope was 2:1; however, guard rail was not economically justified where the embankment cross slope was 3:1.

   The results of the 50 mph analyses are arranged according to increasing lateral offset of the hazard (6, 8, and 10 feet) and length of hazard (100, 500, and 1000 feet) in Tables 19 through 27 and Figures 7 through 15. Each figure is preceded by the table having the results upon which the figure is based.

   In each case the break-even ADT was determined by linear interpolation between annual cost values that were obtained from the computer using the ROADSIDE program. The break-even ADT values were subsequently checked to verify correctness by running the ROADSIDE program using the break-even ADT for the traffic volume.

   Each set of results followed a consistent pattern in that the minimum break-even ADT was always found at the embankment height of 20 feet. This is explained by the fact that for embankments above 20 feet, the cost of placing the embankment continued to increase (due to increasing volume of the earthwork prism), while the severity indices (and hence, accident costs) reached a maximum value at the embankment elevation of 20 feet.

   Thus, the results for embankments higher than 20 feet consistently respond to increasing costs of embankment construction, but an unchanging level of accident severity. This interaction of cost components causes the break-even ADT to increase noticeably for the embankments higher than 20 feet.

   An illustration of this trend may be seen in Table 19 where the minimum break-even ADT is 1537 vehicles per day for lateral offset equal to 6 feet, embankment height 20 feet, length of hazard 100 feet, and cross-slope 2:1. On either side of this break-even 1537 ADT, the resulting values are higher (16 feet has a break-even ADT of 1866 and 30 feet has a break-even ADT of 1865). The trend continues through the embankment height of 100 feet where the break-even ADT is 4162 vehicles per day.

TABLE 19.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 6 FT LATERAL OFFSET, AND 100 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H,(ft)	Length of Obstacle, L, (ft)	Annual Cost ($) for Alternative* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	100	45	454	2271	4543	
3:1	4	100	17	172	858	1715	No
GR	4	125	382	807	2695	5056	GR
2:1	8	100	55	548	2742	5485	
3:1	8	100	21	215	1075	2149	
GR	8	125	426	851	2739	5100	4961
2:1	12	100	64	638	3188	6375	
3:1	12	100	26	255	1276	2552	
GR	12	125	470	895	2783	5144	2552
2:1	16	100	72	723	3613	7227	
3:1	16	100	29	294	1470	2939	
GR	16	125	515	940	2828	5189	1866
2:1	20	100	81	805	4026	8052	
3:1	20	100	33	332	1660	3321	
GR	20	125	559	984	2872	5233	1537
2:1	30	100	81	807	4036	8072	
3:1	30	100	33	332	1660	3321	
GR	30	125	669	1094	2982	5343	1865
2:1	40	100	81	807	4036	8072	
3:1	40	100	33	332	1660	3321	
GR	40	125	779	1204	3892	5453	2184
2:1	60	100	81	807	4036	8072	
3:1	60	100	33	332	1660	3321	
GR	60	125	1000	1425	3313	5674	2843
2:1	80	100	81	807	4036	8072	
3:1	80	100	33	332	1660	3321	
GR	80	125	1221	1646	3534	5895	3502
2:1	100	100	81	807	4036	8072	
3:1	100	100	33	332	1660	3321	
GR	100	125	1442	1867	3755	6116	4162

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

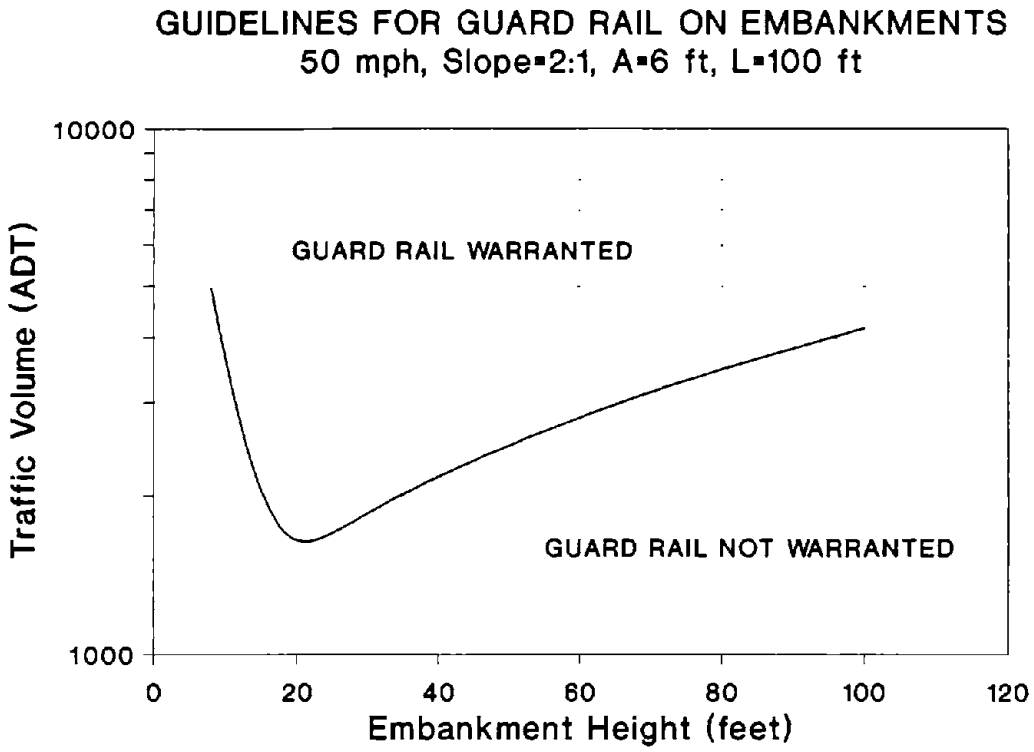

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=6 ft, L=100 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 7.

TABLE 20.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 6 FT LATERAL OFFSET, AND 500 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H,(ft)	Length of Obstacle, L, (ft)	Annual Cost ($) for Alternative* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	500	174	1736	8679	17358	
3:1	4	500	65	645	3225	6450	No
GR	4	525	1323	2781	9264	17366	GR
2:1	8	500	204	2039	10194	20389	
3:1	8	500	79	788	3939	7877	
GR	8	525	1405	2863	9346	17448	2971
2:1	12	500	234	2337	11684	23367	
3:1	12	500	93	927	4637	9273	
GR	12	525	1487	2945	9428	17530	1849
2:1	16	500	263	2631	13153	26307	
3:1	16	500	107	1065	5327	10654	
GR	16	525	1569	3027	9510	17612	1392
2:1	20	500	292	2924	14610	29240	
3:1	20	500	120	1203	6014	12028	
GR	20	525	1651	3109	9592	17694	1144
2:1	30	500	292	2924	14620	29240	
3:1	30	500	120	1203	6014	12028	
GR	30	525	1855	3313	9796	17898	1298
2:1	40	500	292	2924	14620	29240	
3:1	40	500	120	1203	6014	12028	
GR	40	525	2060	3518	10001	18103	1456
2:1	60	500	292	2924	14620	29240	
3:1	60	500	120	1203	6014	12028	
GR	60	525	2470	3928	10411	18513	1770
2:1	80	500	292	2924	14620	29240	
3:1	80	500	120	1203	6014	12028	
GR	80	525	2879	4337	10820	18922	2084
2:1	100	500	292	2924	14620	29240	
3:1	100	500	120	1203	6014	12028	
GR	100	525	3289	4747	11230	19332	2399

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guardrail installed.

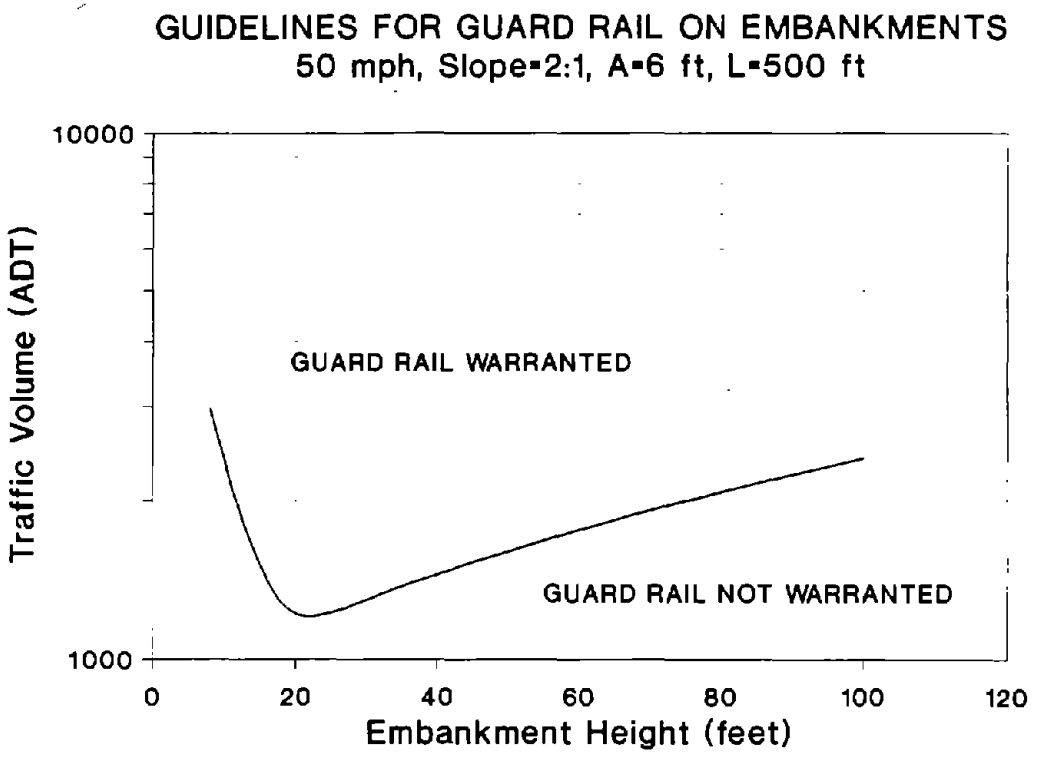

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=6 ft, L=500 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 8.

TABLE 21.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 6 FT LATERAL OFFSET, AND 1000 FT OBSTACLE LENGTH

EMB or GR **	EMB HEIGHT H, (ft)	Length of Obstacle L, (ft)	Annual Cost ($) for Alternative* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	1000	334	3338	16689	33378	
3:1	4	1000	124	1237	6184	12369	
GR	4	1025	2498	5249	17473	32754	7784
2:1	8	1000	390	3902	19509	39019	
3:1	8	1000	150	1504	7519	15037	
GR	8	1025	2627	5378	17602	32883	2745
2:1	12	1000	446	4461	22304	44607	
3:1	12	1000	177	1767	8837	17675	
GR	12	1025	2756	5507	17731	33012	1745
2:1	16	1000	502	5016	25079	50157	
3:1	16	1000	203	2030	10148	20297	
GR	16	1025	2886	5637	17861	33142	1317
2:1	20	1000	557	5570	27841	55701	
3:1	20	1000	229	2291	11456	22912	
GR	20	1025	3015	5766	17990	33271	1079
2:1	30	1000	557	5570	27841	55701	
3:1	30	1000	229	2291	11456	22912	
GR	30	1025	3338	6089	18313	33594	1208
2:1	40	1000	557	5570	27841	55701	
3:1	40	1000	229	2291	11456	22912	
GR	40	1025	3660	6411	18635	33916	1336
2:1	60	1000	557	5570	27841	55701	
3:1	60	1000	229	2291	11456	22912	
GR	60	1025	4306	7057	19281	34562	1593
2:1	80	1000	557	5570	27841	55701	
3:1	80	1000	229	2291	11456	22912	
GR	80	1025	4952	7703	19927	35208	1850
2:1	100	1000	557	5570	27841	55701	
3:1	100	1000	229	2291	11456	22912	
GR	100	1025	5598	8349	20573	35854	2107

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding the listed ADT should have guard rail installed.

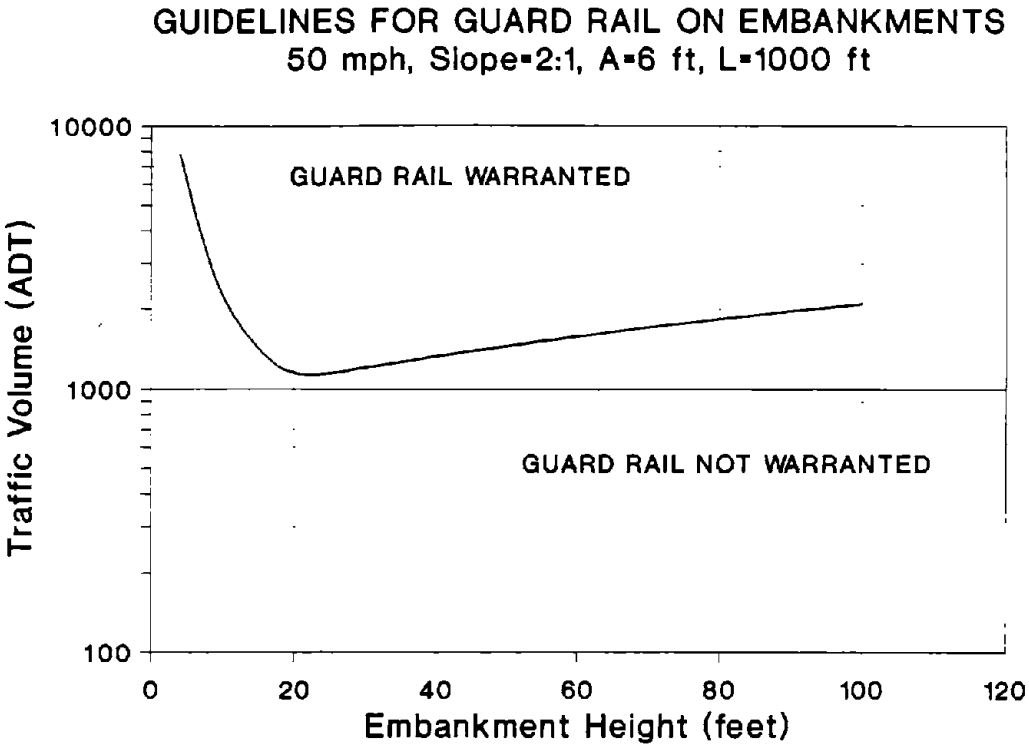

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=6 ft, L=1000 ft
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
Traffic Volume (ADT)
10000
1000
100
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 9.

TABLE 22.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 8 FT LATERAL OFFSET, AND 100 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Length of Obstacle, L, (ft)	Annual Cost ($) for Alternative* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	100	39	392	1959	3918	
3:1	4	100	15	148	740	1479	No
GR	4	125	375	742	2371	4407	GR
2:1	8	100	47	473	2365	4730	
3:1	8	100	19	185	926	1853	
GR	8	125	419	786	2415	4451	5760
2:1	12	100	55	550	2748	5496	
3:1	12	100	22	220	1100	2199	
GR	12	125	463	830	2459	4495	2968
2:1	16	100	62	623	3114	6227	
3:1	16	100	25	253	1266	2532	
GR	16	125	508	875	2504	4540	2169
2:1	20	100	69	694	3468	6937	
3:1	20	100	29	286	1430	2860	
GR	20	125	552	919	2548	4584	1786
2:1	30	100	70	695	3476	6952	
3:1	30	100	29	286	1430	2860	
GR	30	125	662	1029	2658	4694	2160
2:1	40	100	70	695	3476	6952	
3:1	40	100	29	286	1430	2860	
GR	40	125	772	1139	2768	4804	2542
2:1	60	100	70	695	3476	6952	
3:1	60	100	29	286	1430	2860	
GR	60	125	993	1360	2989	5025	3309
2:1	80	100	70	695	3476	6952	
3:1	80	100	29	286	1430	2860	
GR	80	125	1214	1581	3210	5246	4076
2:1	100	100	70	695	3476	6952	
3:1	100	100	29	286	1430	2860	
GR	100	125	1435	1802	3431	5467	4844

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guardrail; locations with traffic exceeding listed ADT should have guard rail installed.

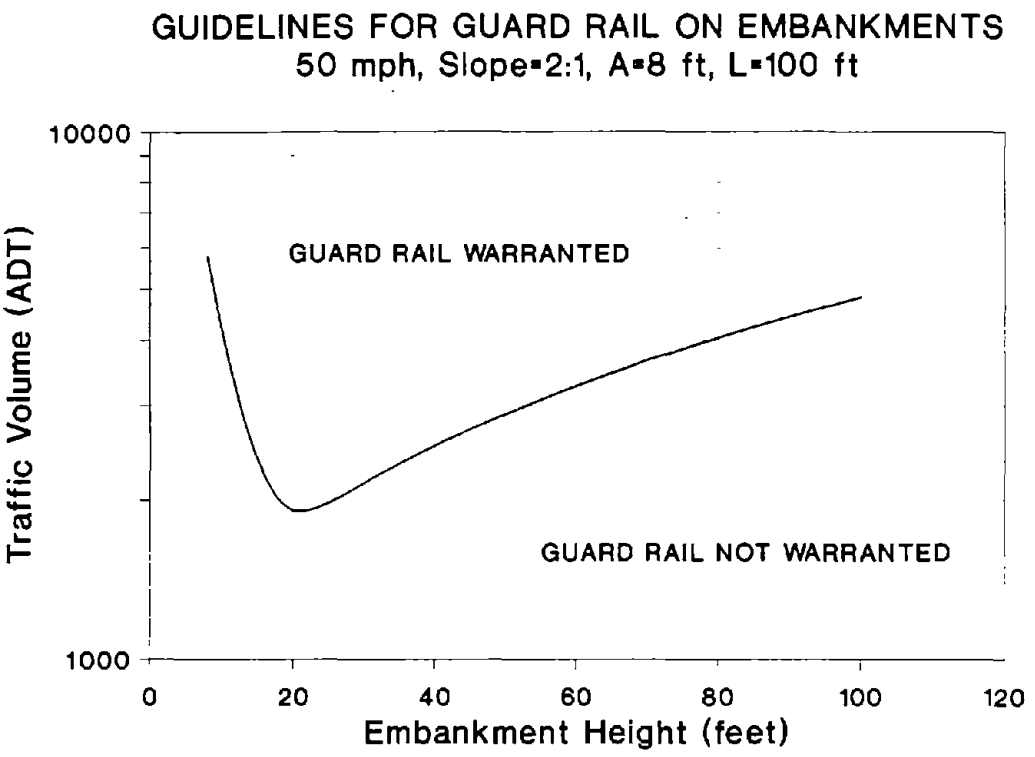

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=8 ft, L=100 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 10.

TABLE 23.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 8 FT LATERAL OFFSET, AND 500 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Length of Obstacle L, (ft)	Annual Cost ($) for Alternative* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	500	150	1497	7485	14970	
3:1	4	500	56	556	2781	5563	No
GR	4	525	1301	2558	8149	15137	GR
2:1	8	500	176	1758	8791	17583	
3:1	8	500	68	679	3396	6792	
GR	8	525	1383	2640	8231	15219	3447
2:1	12	500	201	2015	10075	20149	
3:1	12	500	80	800	3998	7995	
GR	12	525	1465	2722	8313	15301	2145
2:1	16	500	227	2268	11341	22682	
3:1	16	500	92	918	4592	9184	
GR	16	525	1547	2804	8395	15383	1615
2:1	20	500	252	2519	12596	25192	
3:1	20	500	104	1037	5184	10369	
GR	20	525	1629	2886	8477	15465	1327
2:1	30	500	252	2521	12603	25207	
3:1	30	500	104	1037	5184	10369	
GR	30	525	1833	3090	8681	15669	1507
2:1	40	500	252	2521	12604	25207	
3:1	40	500	104	1037	5184	10369	
GR	40	525	2038	3295	8886	15874	1689
2:1	60	500	252	2521	12604	25207	
3:1	60	500	104	1037	5184	10369	
GR	60	525	2448	3705	9296	16284	2054
2:1	80	500	252	2521	12604	25207	
3:1	80	500	104	1037	5184	10369	
GR	80	525	2857	4114	9705	16693	2419
2:1	100	500	252	2521	12604	25207	
3:1	100	500	104	1037	5184	10369	
GR	100	525	3267	4524	10115	17103	2784

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

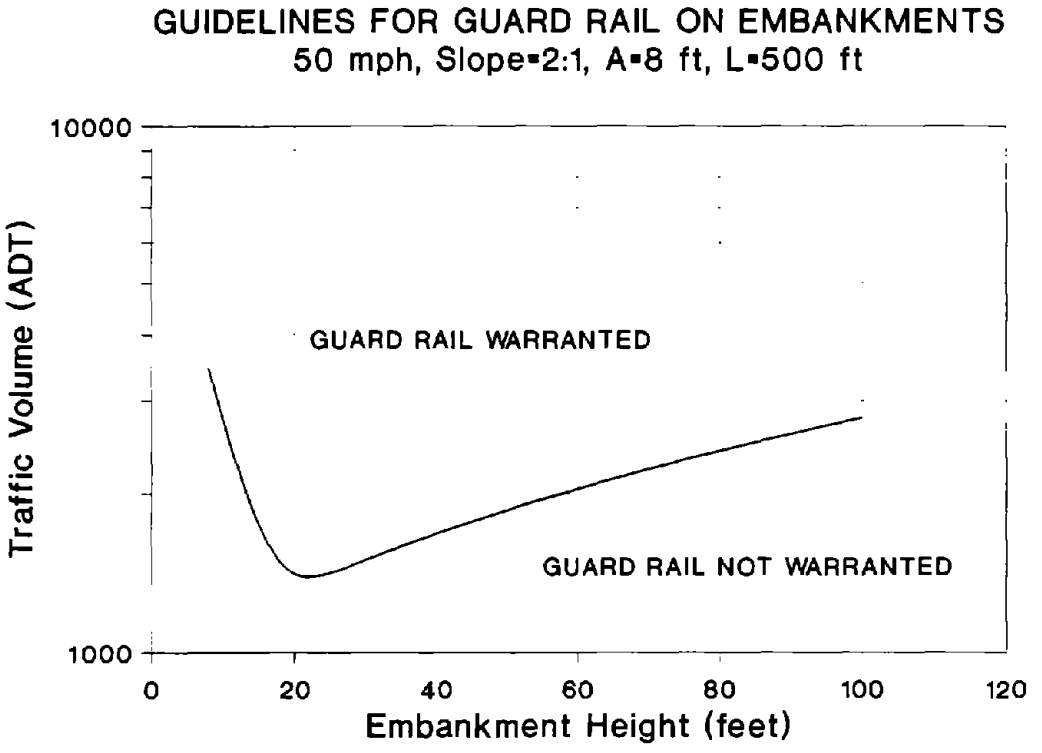

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=8 ft, L=500 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 11.

TABLE 24.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 Ft DRIVING LANE WIDTH, 8 FT LATERAL OFFSET, AND 1000 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Length of Obstacle L, (ft)	Annual Cost ($) for Alternative* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	1000	288	2878	14392	28785	
3:1	4	1000	107	1067	5333	10677	
GR	4	1025	2456	4828	15371	28549	9029
2:1	8	1000	336	3365	16824	33648	
3:1	8	1000	130	1297	6483	12967	
GR	8	1025	2585	4957	15500	28678	3186
2:1	12	1000	385	3847	19233	38466	
3:1	12	1000	152	1524	7620	15240	
GR	12	1025	2714	5086	15629	28807	2494
2:1	16	1000	432	4325	21625	43249	
3:1	16	1000	175	1750	8750	17500	
GR	16	1025	2844	5216	15759	28937	1527
2:1	20	1000	480	4801	24005	48010	
3:1	20	1000	198	1975	9877	19755	
GR	20	1025	2973	5345	15888	29066	1251
2:1	30	1000	480	4803	24013	48025	
3:1	30	1000	198	1975	9877	19755	
GR	30	1025	3296	5668	16211	29389	1399
2:1	40	1000	480	4803	24013	48026	
3:1	40	1000	198	1975	9877	19755	
GR	40	1025	3618	5990	16533	29711	1548
2:1	60	1000	480	4803	24013	48026	
3:1	60	1000	198	1975	9877	19755	
GR	60	1025	4264	6636	17179	30357	1846
2:1	80	1000	480	4803	24013	48026	
3:1	80	1000	198	1975	9877	19755	
GR	80	1025	4910	7282	17825	31003	2144
2:1	100	1000	480	4803	24013	48026	
3:1	100	1000	198	1975	9877	19755	
GR	100	1025	5556	7928	18471	31649	2442

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

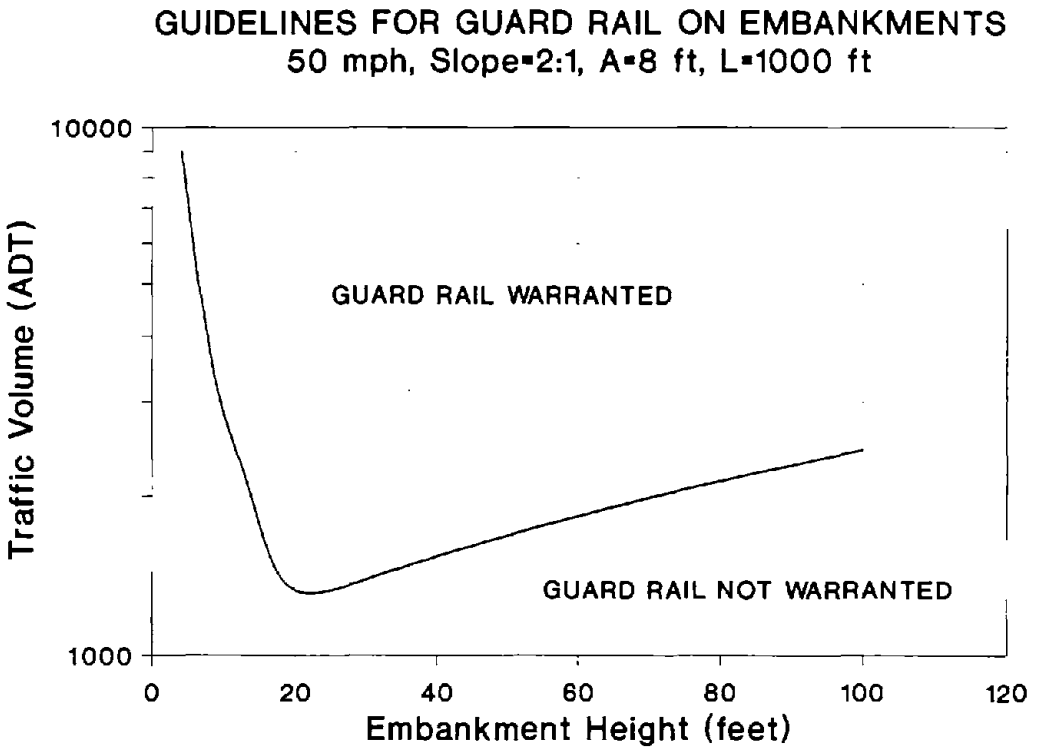

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=8 ft, L=1000 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 12.

TABLE 25.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 10 FT LATERAL OFFSET, AND 100 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost ($) for Alternative* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	100	34	338	1690	3380	
3:1	4	100	13	128	638	1276	No
GR	4	125	370	686	2091	3848	GR
2:1	8	100	41	408	2039	4079	
3:1	8	100	16	160	798	1597	
GR	8	125	414	730	2135	3893	6696
2:1	12	100	47	474	2368	4737	
3:1	12	100	19	189	947	1894	
GR	12	125	458	774	2179	3936	3454
2:1	16	100	54	537	2683	5366	
3:1	16	100	22	218	1090	2181	
GR	16	125	503	819	2224	3981	2522
2:1	20	100	60	598	2988	5975	
3:1	20	100	25	246	1231	2463	
GR	20	125	547	863	2268	4025	2076
2:1	30	100	60	599	2993	5987	
3:1	30	100	25	246	1231	2463	
GR	30	125	657	973	2378	4135	2513
2:1	40	100	60	599	2993	5987	
3:1	40	100	25	246	1231	2463	
GR	40	125	767	1083	2488	4245	2958
2:1	60	100	60	599	2993	5987	
3:1	60	100	25	246	1231	2463	
GR	60	125	988	1304	2709	4466	3851
2:1	80	100	60	599	2993	5987	
3:1	80	100	25	246	1231	2463	
GR	80	125	1209	1525	2930	4687	4745
2:1	100	100	60	599	2993	5987	
3:1	100	100	25	246	1231	2463	
GR	100	125	1430	1746	3151	4908	5639

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

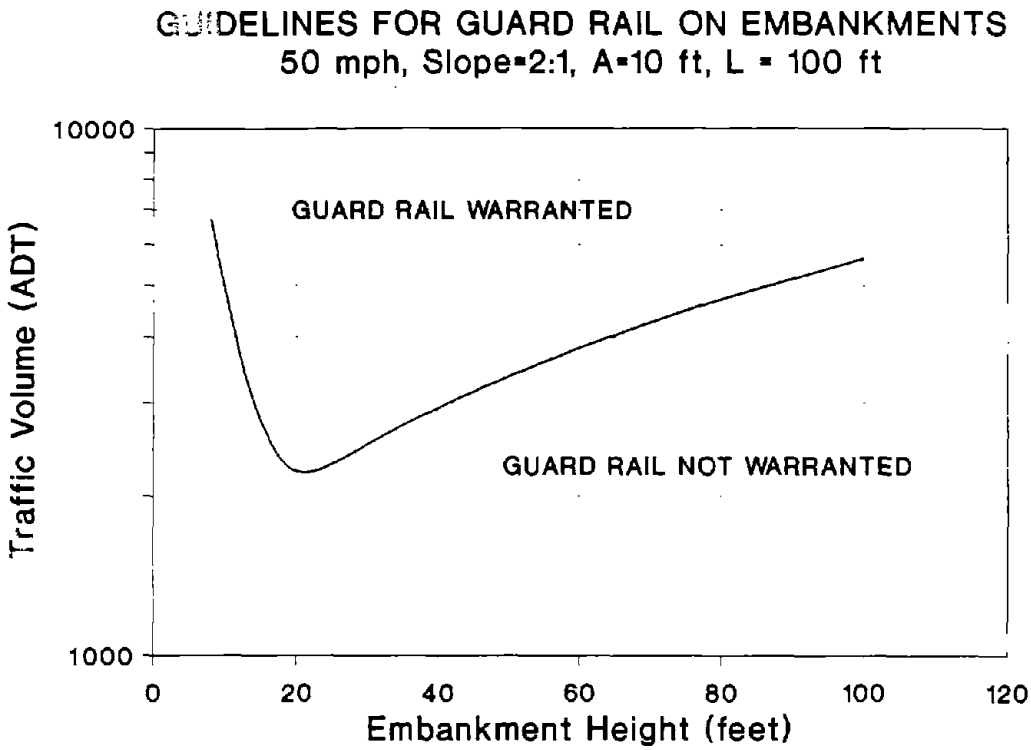

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=10 ft, L = 100 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 13.

TABLE 26.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 10 FT LATERAL OFFSET, AND 500 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	500	129	1291	6456	12911	
3:1	4	500	48	480	2399	4797	No
GR	4	525	1281	2366	7188	13215	GR
2:1	8	500	152	1516	7582	15163	
3:1	8	500	59	586	2928	5857	
GR	8	525	1363	2448	7270	13297	3997
2:1	12	500	174	1737	8687	17374	
3:1	12	500	69	689	3446	6893	
GR	12	525	1445	2530	7352	13379	2490
2:1	16	500	196	1956	9778	19556	
3:1	16	500	79	792	3959	7918	
GR	16	525	1527	2612	7434	13461	1875
2:1	20	500	217	2172	10859	21718	
3:1	20	500	89	894	4469	8938	
GR	20	525	1609	2694	7516	13543	1540
2:1	30	500	217	2173	10865	21730	
3:1	30	500	89	894	4469	8938	
GR	30	525	1813	2898	7720	13747	1749
2:1	40	500	217	2173	10865	21730	
3:1	40	500	89	894	4469	8938	
GR	40	525	2018	3103	7925	13952	1961
2:1	60	500	217	2173	10865	21730	
3:1	60	500	89	894	4469	8938	
GR	60	525	2428	3513	8335	14362	2385
2:1	80	500	217	2173	10865	21730	
3:1	80	500	89	894	4469	8938	
GR	80	525	2837	3922	8744	14771	2808
2:1	100	500	217	2173	10865	21730	
3:1	100	500	89	894	4469	8938	
GR	100	525	3247	4332	9154	15181	3232

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

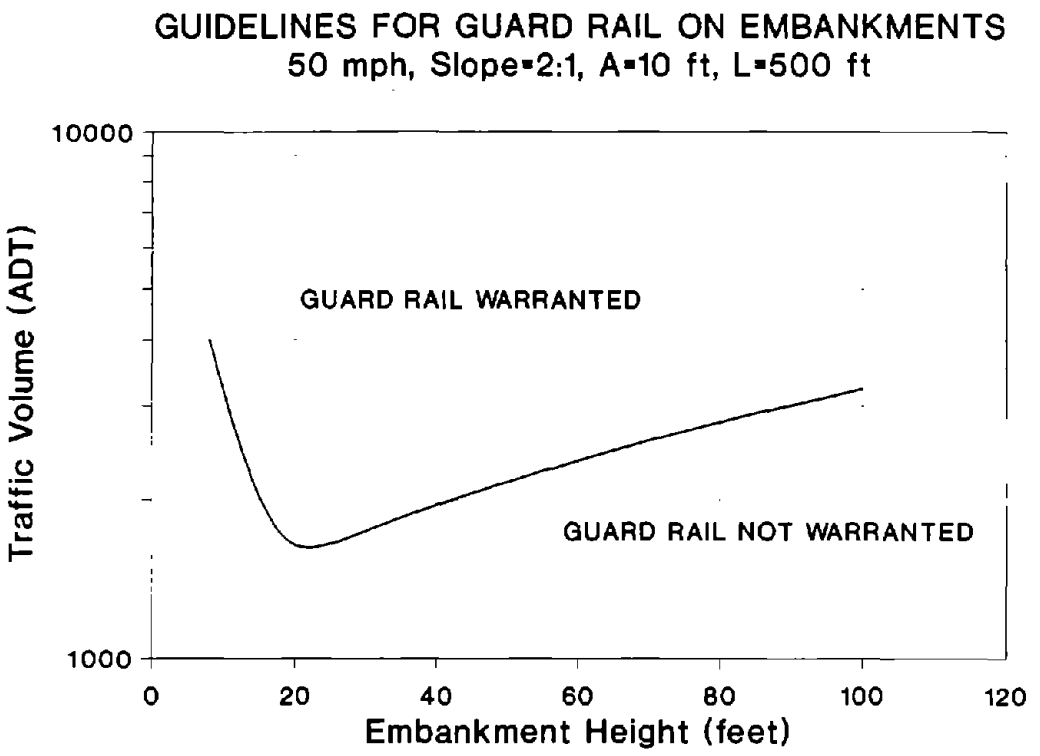

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=10 ft, L=500 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 14.

TABLE 27.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 50 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 10 FT LATERAL OFFSET, AND 1000 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	1000	248	2483	12413	24835	
3:1	4	1000	92	920	4600	9199	No
GR	4	1025	2420	4466	13558	24924	GR
2:1	8	1000	290	2902	14509	29018	
3:1	8	1000	112	1118	5591	11182	
GR	8	1025	2549	4595	13687	25053	3693
2:1	12	1000	332	3317	16585	33171	
3:1	12	1000	131	1314	6571	13141	
GR	12	1025	2678	4724	13816	25182	2347
2:1	16	1000	373	3729	18647	37294	
3:1	16	1000	151	1509	7545	15089	
GR	16	1025	2808	4854	13946	25312	1772
2:1	20	1000	414	4140	20699	41397	
3:1	20	1000	170	1703	8517	17033	
GR	20	1025	2937	5306	14075	25441	1452
2:1	30	1000	414	4141	20704	41409	
3:1	30	1000	170	1703	8517	17033	
GR	30	1025	3260	5306	14398	25764	1624
2:1	40	1000	414	4141	20704	41409	
3:1	40	1000	170	1703	8517	17033	
GR	40	1025	3582	5628	14720	26086	1796
2:1	60	1000	414	4141	20704	41409	
3:1	60	1000	170	1703	8517	17033	
GR	60	1025	4228	6274	15366	26732	2142
2:1	80	1000	414	4141	20704	41409	
3:1	80	1000	170	1703	8517	17033	
GR	80	1025	4874	6920	16012	27378	2488
2:1	100	1000	414	4141	20704	41409	
3:1	100	1000	170	1703	8517	17033	
GR	100	1025	5520	7566	16658	28024	2834

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

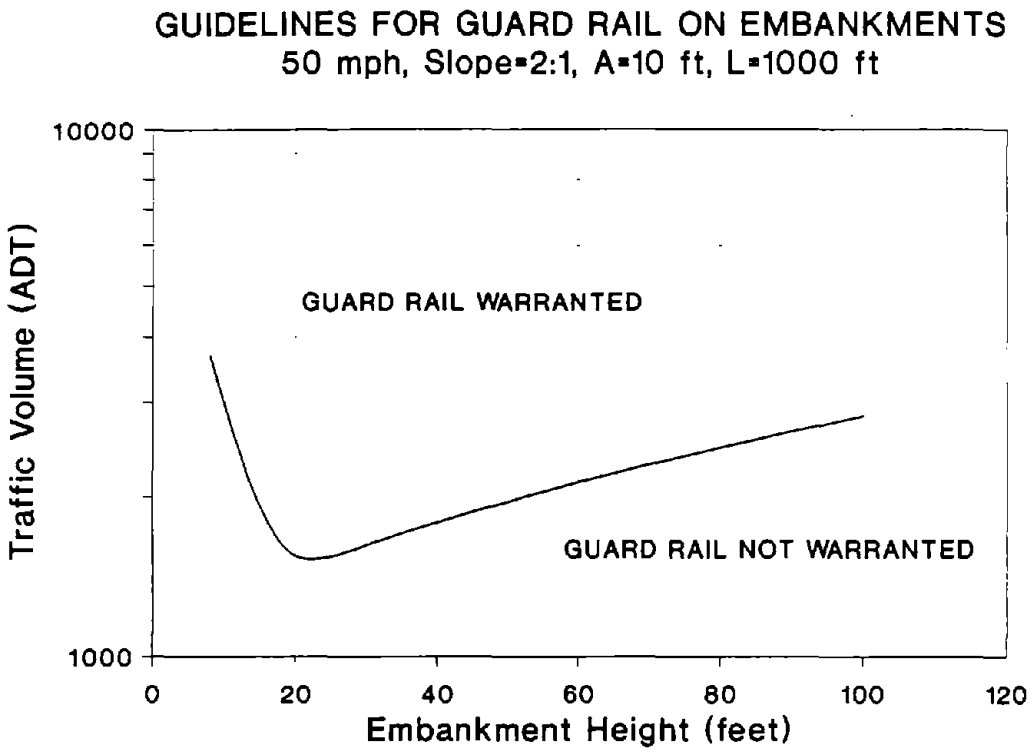

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
50 mph, Slope=2:1, A=10 ft, L=1000 ft
10000
1000
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 15.

4. For a design speed of 60 mph, guard rail installation was found to be economically justified for all situations where the embankment cross slope was 2:1; however, guard rail was not economically justified where the embankment cross slope was 3:1.

   The results of the 60 mph analyses are arranged according to increasing lateral offset of the hazard (6, 8, and 10 feet) and length of hazard (100, 500, and 1000 feet) in Tables 28 through 36 and Figures 16 through 24. Each figure is preceded by the table having the results upon which the figure is based.

   In each case the break-even ADT was determined by linear interpolation between annual cost values that were determined on the computer using the ROADSIDE program. The break-even ADT values were subsequently checked to verify correctness by running the ROADSIDE program using the break-even ADT for the traffic volume.

   As was the case with the 50 mph results, each set of 2:1 cross slope conditions evaluated at 60 mph yielded a minimum break-even ADT at the embankment height of 20 feet. The results for embankments higher than 20 feet follow a noticeable trend of increasing break-even ADT due to increasing initial cost of constructing the higher embankments.

   Although the 3:1 cross slope conditions did not generate an economic justification for guard rail installation in the range of input parameters investigated at 60 mph, it is very important to observe that for ADT's approaching 10000 vehicles per day, the total annual cost for guard rail at embankment heights of 20 feet and greater were closely approached by the total annual cost of not having the guard rail in place. In other words, in the higher volume ranges at 60 mph design speed it is almost economically justified to install the guard rail on a 3:1 cross slope. In practical terms, then, if there might be any special obstacle or hazard on these higher embankments, the ROADSIDE program should be applied to that situation in order to determine if the guard rail should be installed.

TABLE 28.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 6 FT LATERAL OFFSET, AND 100 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	100	109	1093	5466	10932	
3:1	4	100	41	410	2052	4104	
GR	4	125	433	1313	5227	10118	2917
2:1	8	100	144	1436	7178	14355	
3:1	8	100	50	501	2504	5007	
GR	8	125	477	1357	5271	10162	827
2:1	12	100	177	1771	8857	17713	
3:1	12	100	66	656	3279	6557	
GR	12	125	521	1401	5315	10206	534
2:1	16	100	210	2098	10491	20982	
3:1	16	100	81	806	4030	8060	
GR	16	125	566	1446	5360	10251	418
2:1	20	100	242	2416	12082	24164	
3:1	20	100	95	953	4765	9531	
GR	20	125	610	1490	5404	10295	356
2:1	30	100	244	2438	12189	24378	
3:1	30	100	95	954	4771	9541	
GR	30	125	720	1600	5514	10405	426
2:1	40	100	244	2440	12202	24404	
3:1	40	100	95	954	4771	9541	
GR	40	125	830	1710	5624	10515	501
2:1	60	100	244	2440	12202	24404	
3:1	60	100	95	954	4771	9541	
GR	60	125	1051	1931	5845	10736	652
2:1	80	100	244	2440	12202	24404	
3:1	80	100	95	954	4771	9541	
GR	80	125	1272	2152	6066	10957	803
2:1	100	100	244	2440	12202	24404	
3:1	100	100	95	954	4771	9541	
GR	100	125	1493	2373	6287	11178	954

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Breakeven ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installled.

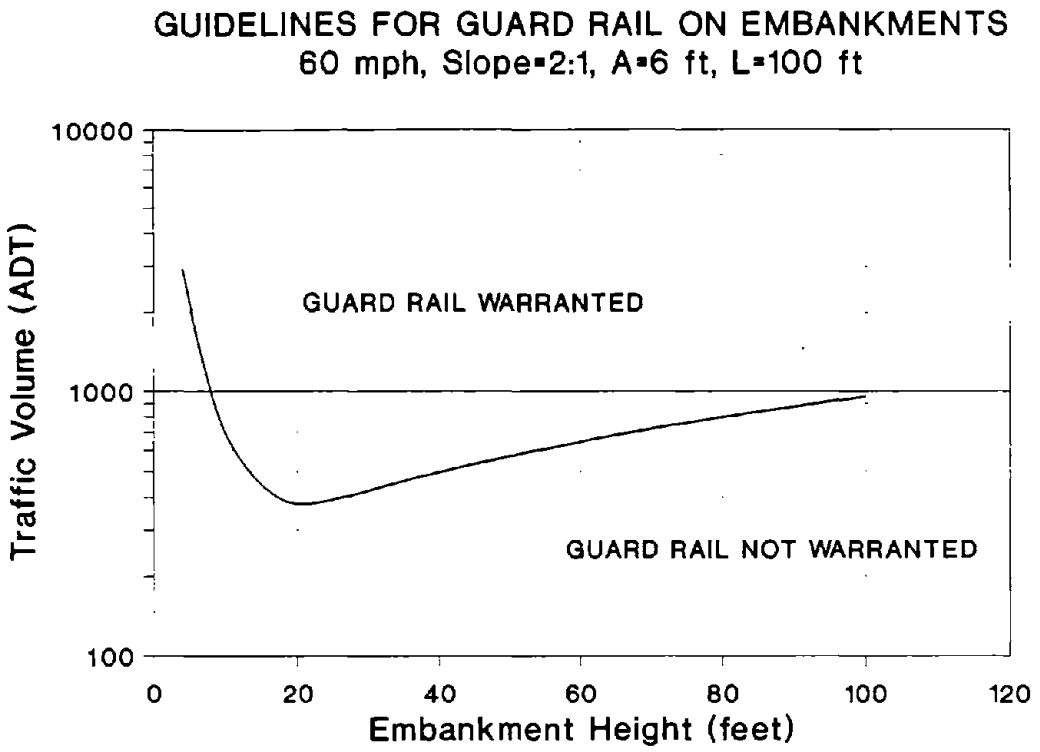

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=6 ft, L=100 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 16.

TABLE 29.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 6 FT LATERAL OFFSET, AND 500 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	500	393	3935	19673	39347	
3:1	4	500	144	1443	7217	14433	
GR	4	525	1477	4327	16993	32825	1510
2:1	8	500	496	4961	24806	49611	
3:1	8	500	169	1691	8454	16907	
GR	8	525	1559	4409	17075	32907	691
2:1	12	500	598	5981	29905	59811	
3:1	12	500	218	2176	10880	21760	
GR	12	525	1641	4491	17157	32989	471
2:1	16	500	699	6992	34960	69921	
3:1	16	500	266	2657	13283	26566	
GR	16	525	1723	4573	17239	33071	368
2:1	20	500	799	7994	39972	79944	
3:1	20	500	313	3134	15670	31340	
GR	20	525	1805	4655	17321	33153	308
2:1	30	500	802	8016	40079	80158	
3:1	30	500	314	3135	15675	31350	
GR	30	525	2009	4859	17525	33357	349
2:1	40	500	802	8018	40092	80184	
3:1	40	500	314	3135	15675	31350	
GR	40	525	2214	5064	17730	33562	391
2:1	60	500	802	8018	40092	80185	
3:1	60	500	314	3135	15675	31350	
GR	60	525	2624	5474	18140	33972	476
2:1	80	500	802	8018	40092	80185	
3:1	80	500	314	3135	15675	31350	
GR	80	525	3033	5883	18549	34381	560
2:1	100	500	802	8018	40092	80185	
3:1	100	500	314	3135	15675	31350	
GR	100	525	3443	6293	18959	34791	644

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

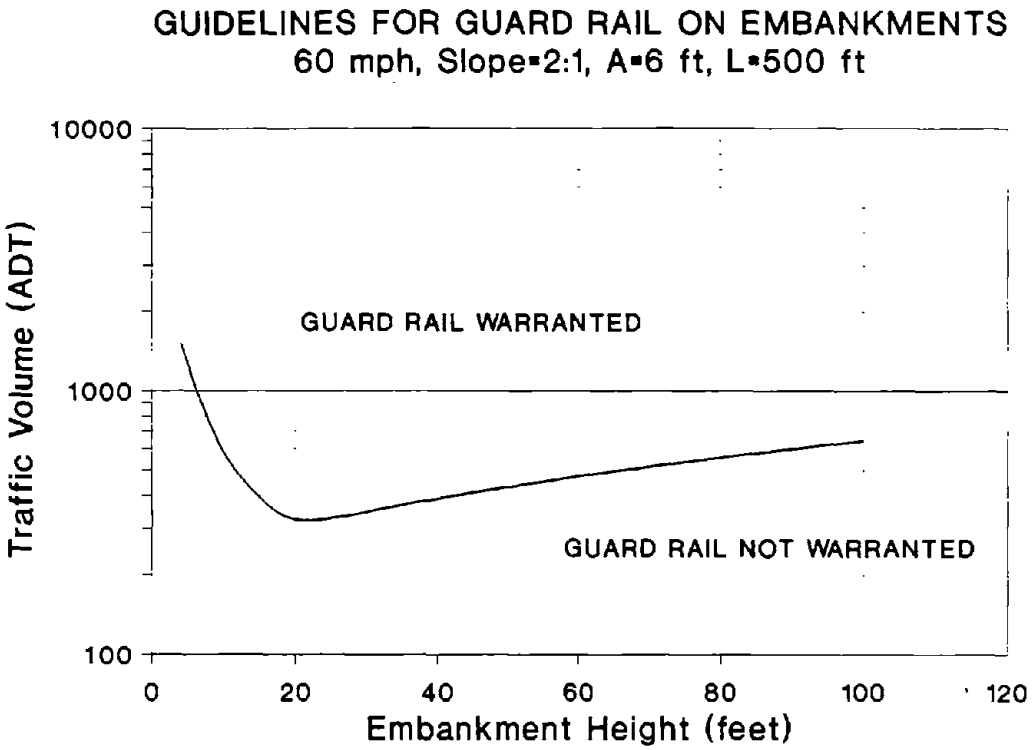

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=6 ft, L=500 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 17.

TABLE 30.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVIMG LANE WIDTH, 6 FT LATERAL OFFSET, AND 1000 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	1000	749	7486	37432	74865	
3:1	4	1000	273	2735	13673	27345	
GR	4	1025	2783	8094	31701	61209	1384
2:1	8	1000	937	9368	46841	93681	
3:1	8	1000	318	3178	15891	31783	
GR	8	1025	2912	8223	31830	61338	670
2:1	12	1000	1124	11243	56216	112433	
3:1	12	1000	408	4076	20382	40764	
GR	12	1025	3041	8352	31959	61467	459
2:1	16	1000	1311	13109	65547	131095	
3:1	16	1000	497	4970	24849	49698	
GR	16	1025	3171	8482	32087	61597	358
2:1	20	1000	1497	14967	74835	149670	
3:1	20	1000	586	5860	29300	58601	
GR	20	1025	3300	8611	32218	61726	299
2:1	30	1000	1499	14988	74942	149884	
3:1	30	1000	586	5861	29306	58611	
GR	30	1025	3623	8934	32541	62049	334
2:1	40	1000	1499	14991	74955	149910	
3:1	40	1000	586	5861	29306	58611	
GR	40	1025	3945	9256	32863	62371	369
2:1	60	1000	1499	14991	74955	149910	
3:1	60	1000	586	5861	29306	58611	
GR	60	1025	4591	9902	33509	63017	440
2:1	80	1000	1499	14991	74955	149910	
3:1	80	1000	586	5861	29306	58611	
GR	80	1025	5237	10548	34155	63663	511
2:1	100	1000	1499	14991	74955	149910	
3:1	100	1000	586	5861	29306	58611	
GR	100	1025	5883	11194	34801	64309	582

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

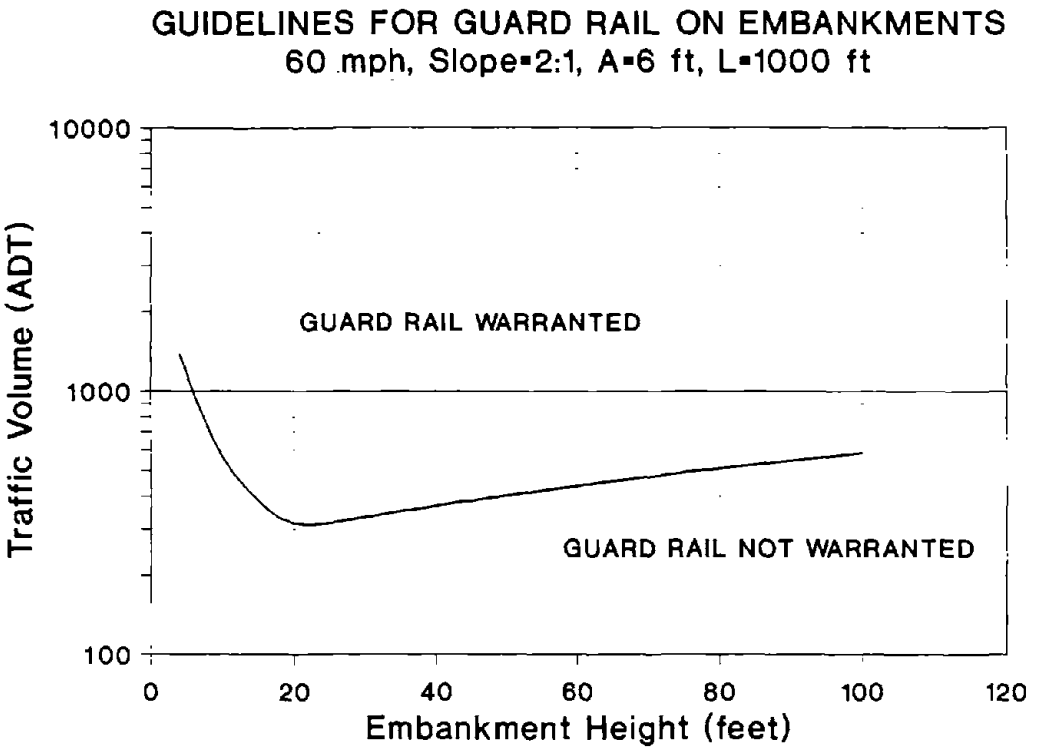

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=6 ft, L=1000 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 18.

TABLE 31.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 8 FT LATERAL OFFSET, AND 100 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	100	97	967	4833	9665	
3:1	4	100	36	363	1814	3629	
GR	4	125	421	1199	4658	8980	3280
2:1	8	100	127	1269	6346	12692	
3:1	8	100	44	443	2213	4426	
GR	8	125	465	1243	4702	9024	935
2:1	12	100	157	1566	7829	15658	
3:1	12	100	58	579	2897	5793	
GR	12	125	509	1287	4746	9068	602
2:1	16	100	185	1854	9270	18541	
3:1	16	100	71	712	3559	7119	
GR	16	125	554	1332	4791	9113	473
2:1	20	100	213	2135	10673	21346	
3:1	20	100	84	842	4208	8416	
GR	20	125	598	1376	4835	9157	403
2:1	30	100	215	2152	10762	21525	
3:1	30	100	84	842	4212	8424	
GR	30	125	708	1486	4945	9267	483
2:1	40	100	215	2154	10772	21545	
3:1	40	100	84	842	4212	8424	
GR	40	125	818	1596	5055	9377	568
2:1	60	100	215	2154	10772	21545	
3:1	60	100	84	842	4212	8424	
GR	60	125	1039	1817	5276	9598	740
2:1	80	100	215	2154	10772	21545	
3:1	80	100	84	842	4212	8424	
GR	80	125	1260	2038	5497	9819	911
2:1	100	100	215	2154	10772	21545	
3:1	100	100	84	842	4212	8424	
GR	100	125	1472	2259	5718	10040	1076

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

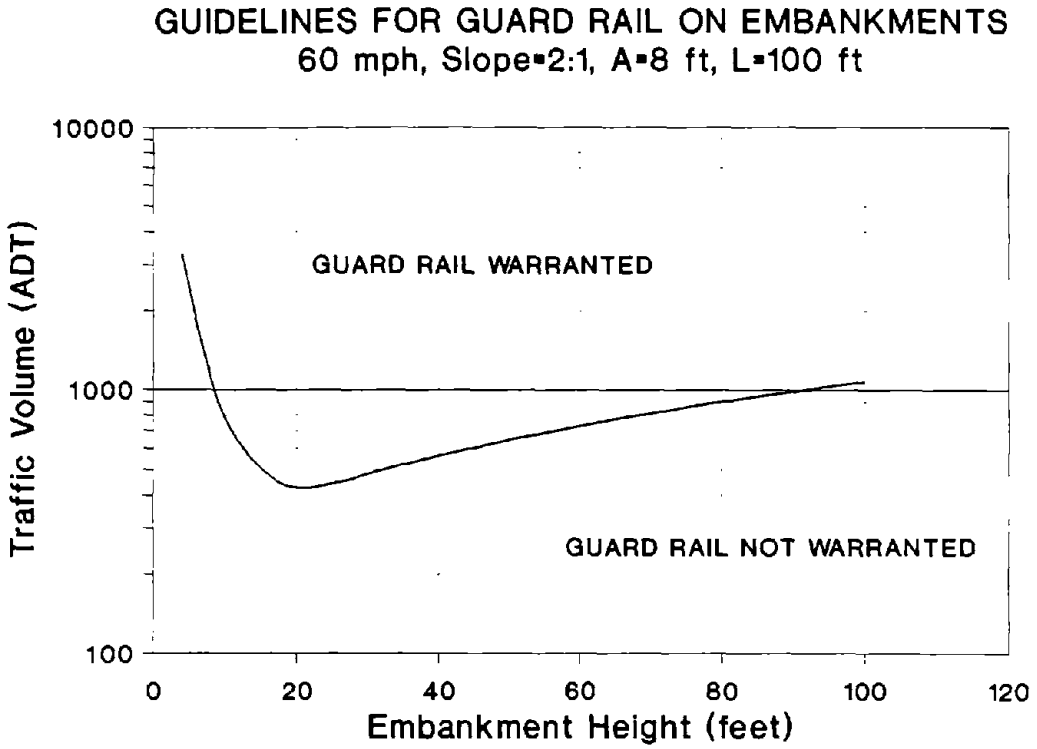

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=8 ft, L=100 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 19.

TABLE 32.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 8 FT LATERAL OFFSET, AND 500 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	500	347	3470	17352	34704	
3:1	4	500	127	1273	6365	12731	
GR	4	525	1440	3953	15124	29087	1713
2:1	8	500	438	4376	21880	43759	
3:1	8	500	149	1491	7456	14912	
GR	8	525	1552	4035	15206	29169	785
2:1	12	500	528	5275	26377	52753	
3:1	12	500	192	1919	9696	19190	
GR	12	525	1604	4117	15288	29251	533
2:1	16	500	617	6167	30833	61665	
3:1	16	500	234	2343	11713	23426	
GR	16	525	1686	4199	15370	29333	417
2:1	20	500	705	7050	32250	70499	
3:1	20	500	276	2763	13817	27633	
GR	20	525	1768	4281	15452	29415	350
2:1	30	500	707	7068	35339	70678	
3:1	30	500	276	2764	13817	27633	
GR	30	525	1972	4485	15452	29619	396
2:1	40	500	707	7070	35349	70698	
3:1	40	500	276	2764	13821	27633	
GR	40	525	2177	4690	15861	29824	443
2:1	60	500	707	7070	35349	70698	
3:1	60	500	276	2764	13821	27633	
GR	60	525	2587	5100	16271	30234	539
2:1	80	500	707	7070	35349	70698	
3:1	80	500	276	2764	13821	27633	
GR	80	525	2996	5509	16680	30643	634
2:1	100	500	707	7070	35349	70698	
3:1	100	500	276	2764	13821	27633	
GR	100	525	3406	5919	17090	31053	730

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

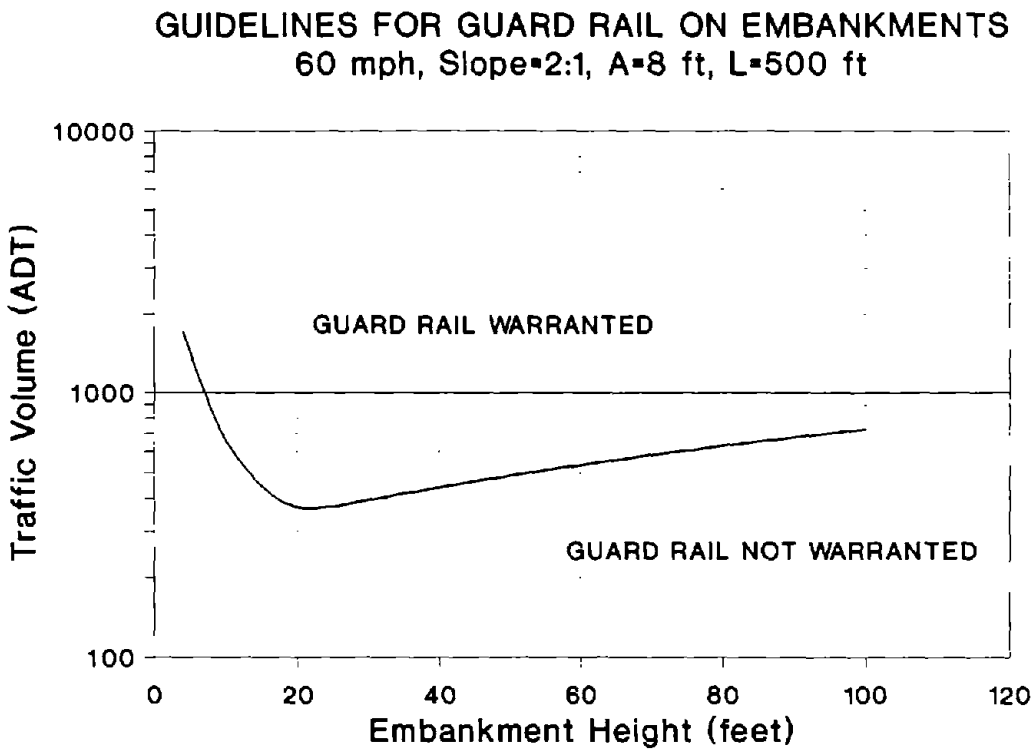

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=8 ft, L=500 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 20.

TABLE 33.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 8 FT LATERAL OFFSET, AND 1000 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	1000	660	6600	33001	66002	
3:1	4	1000	241	2411	12054	24108	
GR	4	1025	2713	7396	28207	54221	1570
2:1	8	1000	826	8259	41296	82593	
3:1	8	1000	280	2802	14010	28020	
GR	8	1025	2842	7525	28336	54350	760
2:1	12	1000	991	9912	49561	99123	
3:1	12	1000	359	3594	17968	35936	
GR	12	1025	2971	7654	28465	54479	520
2:1	16	1000	1156	11557	57785	115571	
3:1	16	1000	438	4381	21905	43810	
GR	16	1025	3101	7784	28595	54609	406
2:1	20	1000	1319	13194	65970	131940	
3:1	20	1000	517	5166	25828	51655	
GR	20	1025	3230	7913	28724	54738	339
2:1	30	1000	1321	13212	66059	132119	
3:1	30	1000	517	5166	25831	51663	
GR	30	1025	3553	8236	29047	55383	378
2:1	40	1000	1321	13214	66069	132139	
3:1	40	1000	517	5166	25831	51663	
GR	40	1025	3875	8558	29369	55383	419
2:1	60	1000	1321	13214	66070	132139	
3:1	60	1000	517	5166	25831	51663	
GR	60	1025	4521	9204	30015	56029	499
2:1	80	1000	1321	13214	66070	132139	
3:1	80	1000	517	5166	25831	51663	
GR	80	1025	5167	9850	30661	56675	580
2:1	100	1000	1321	13214	66070	132139	
3:1	100	1000	517	5166	25831	51663	
GR	100	1025	5813	10496	31307	57321	660

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

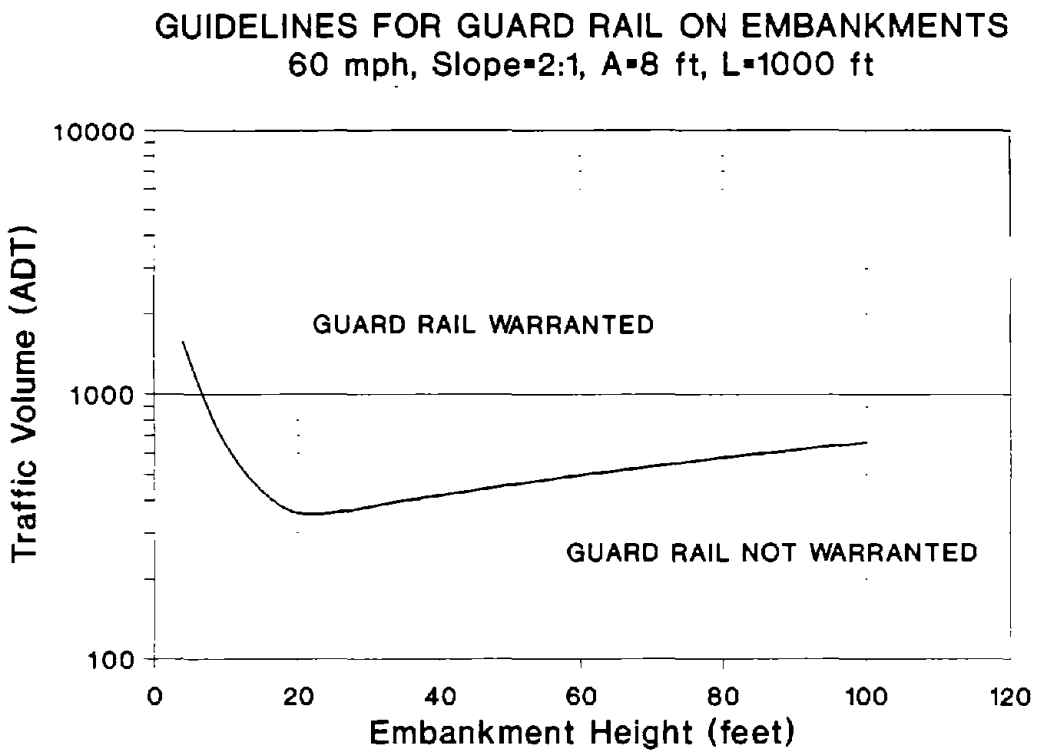

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=8 ft, L=1000 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 21.

TABLE 34.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 10 FT LATERAL OFFSET, AND 100 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	100	86	859	4297	8593	
3:1	4	100	32	323	1613	3226	
GR	4	125	412	1103	4178	8022	3689
2:1	8	100	113	1128	5640	12281	
3:1	8	100	39	393	1966	3932	
GR	8	125	456	1147	4222	8066	1053
2:1	12	100	139	1391	6955	13910	
3:1	12	100	51	514	2572	5143	
GR	12	125	500	1191	4266	8110	679
2:1	16	100	165	1646	8232	16464	
3:1	16	100	63	632	3159	6317	
GR	16	125	545	1236	4311	8155	533
2:1	20	100	189	1895	9474	18948	
3:1	20	100	75	747	3733	7466	
GR	20	125	589	1280	4355	8199	455
2:1	30	100	191	1910	9548	19096	
3:1	30	100	75	747	3736	7472	
GR	30	125	699	1390	4465	8309	545
2:1	40	100	191	1911	9556	19112	
3:1	40	100	75	747	3736	7472	
GR	40	125	809	1500	4575	8419	641
2:1	60	100	191	1911	9556	19112	
3:1	60	100	75	747	3736	7472	
GR	60	125	1030	1721	4796	8640	834
2:1	80	100	191	1911	9556	19112	
3:1	80	100	75	747	3736	7472	
GR	80	125	1251	1942	5017	8861	1027
2:1	100	100	191	1911	9556	19112	
3:1	100	100	75	747	3736	7472	
GR	100	125	1481	2163	5238	9082	1221

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

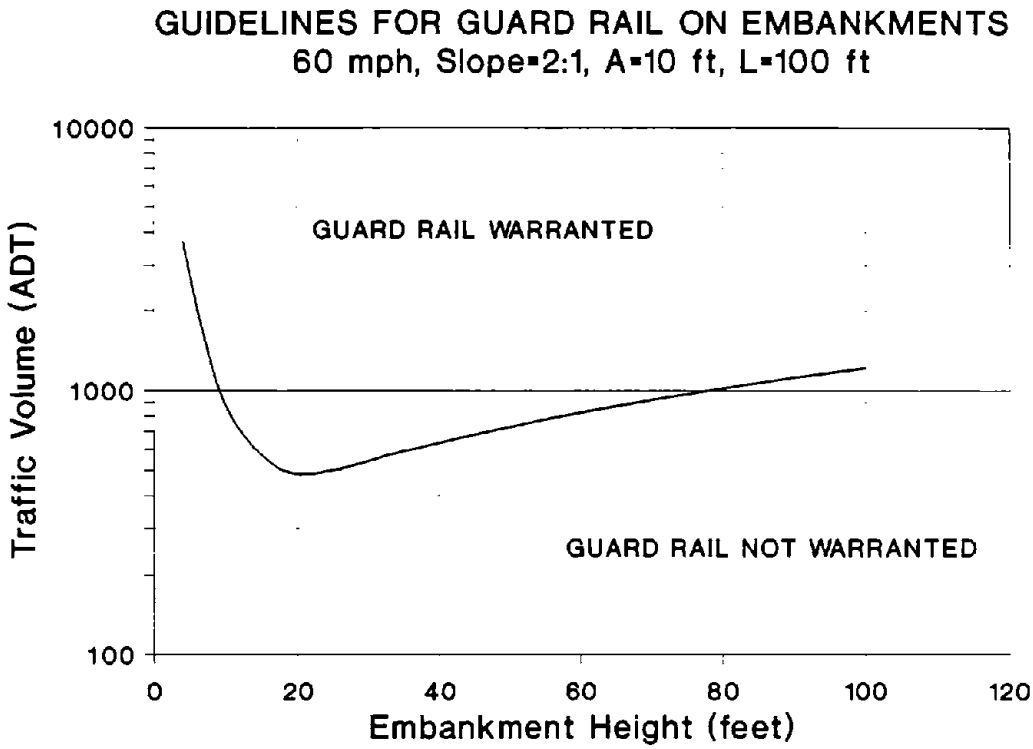

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=10 ft, L=100 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 22.

TABLE 35.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 10 FT LATERAL OFFSET, AND 500 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	500	308	3084	15418	30836	
3:1	4	500	113	1131	5656	11311	
GR	4	525	1409	1642	13568	25976	1927
2:1	8	500	389	3888	19439	38879	
3:1	8	500	132	1325	6624	13247	
GR	8	525	1491	3724	13650	26058	883
2:1	12	500	469	4686	23432	46863	
3:1	12	500	170	1704	8522	17044	
GR	12	525	1573	3806	13732	26140	602
2:1	16	500	548	5477	27386	54773	
3:1	16	500	208	2080	10402	20803	
GR	16	525	1655	3888	13814	26222	470
2:1	20	500	626	6261	31306	62612	
3:1	20	500	245	2454	12269	24538	
GR	20	525	1737	3970	13896	26304	394
2:1	30	500	628	6276	31380	62761	
3:1	30	500	245	2454	12272	24544	
GR	30	525	1941	4174	14100	26508	446
2:1	40	500	628	6278	31388	62776	
3:1	40	500	245	2454	12272	24544	
GR	40	525	2146	4379	14715	26713	500
2:1	60	500	628	6278	31388	62776	
3:1	60	500	245	2454	12272	24544	
GR	60	525	2556	4789	14715	27123	608
2:1	80	500	628	6278	31388	62776	
3:1	80	500	245	2454	12272	24544	
GR	80	525	2965	5198	15124	27532	715
2:1	100	500	628	6278	31388	62776	
3:1	100	500	245	2454	12272	24544	
GR	100	525	3375	5608	15534	27942	824

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

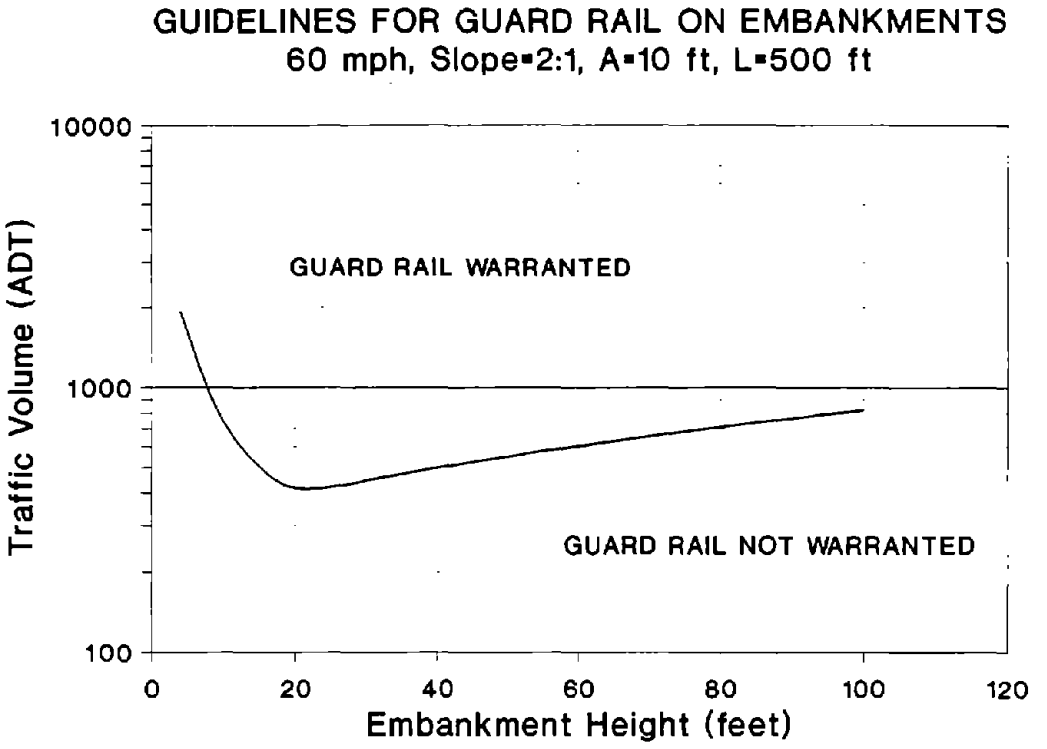

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=10 ft, L=500 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 23.

TABLE 36.

EMBANKMENT vs. GUARD RAIL ANNUAL COST COMPARISONS: 60 MPH DESIGN SPEED, 11 FT DRIVING LANE WIDTH, 10 FT LATERAL OFFSET, AND 1000 FT OBSTACLE LENGTH

EMB or GR **	EMB Height H, (ft)	Obstacle Length L, (ft)	Annual Cost for Alternative ($)* Average Daily Traffic (ADT) 100	1000	5000	10000	Break-Even ADT***
2:1	4	1000	586	5864	29319	58639	
3:1	4	1000	214	2142	10709	21419	
GR	4	1025	2655	6815	25306	48418	1766
2:1	8	1000	734	7338	36688	73376	
3:1	8	1000	249	2489	12446	24892	
GR	8	1025	2784	6944	25435	48547	855
2:1	12	1000	881	8806	44028	102659	
3:1	12	1000	319	3192	15960	38911	
GR	12	1025	2913	7073	25564	48676	586
2:1	16	1000	1027	10266	51329	117192	
3:1	16	1000	389	3891	19455	45877	
GR	16	1025	3043	7203	25694	48806	457
2:1	20	1000	1172	11719	58596	117341	
3:1	20	1000	4592	4588	22939	45883	
GR	20	1025	3495	7332	25823	48935	382
2:1	30	1000	1173	11734	58670	117356	
3:1	30	1000	459	4588	22942	45883	
GR	30	1025	3495	7655	26146	49528	426
2:1	40	1000	1174	11736	58678	117356	
3:1	40	1000	459	4588	22942	45883	
GR	40	1025	3817	7977	26468	49580	472
2:1	60	1000	1174	11736	58678	117356	
3:1	60	1000	459	4588	22942	45883	
GR	60	1025	4463	8623	27114	50226	562
2:1	80	1000	1174	11736	58678	117356	
3:1	80	1000	459	4588	22942	45883	
GR	80	1025	5109	9269	27760	50872	653
2:1	100	1000	1174	11736	58678	117356	
3:1	100	1000	459	4588	22942	45883	
GR	100	1025	5755	9915	28406	51518	744

* Lowest annual cost indicates best alternative for condition evaluated.
** EMB = Embankment stated as cross slope or height. GR = Guard rail.
*** Break-even ADT for 2:1 cross slope embankment vs. guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

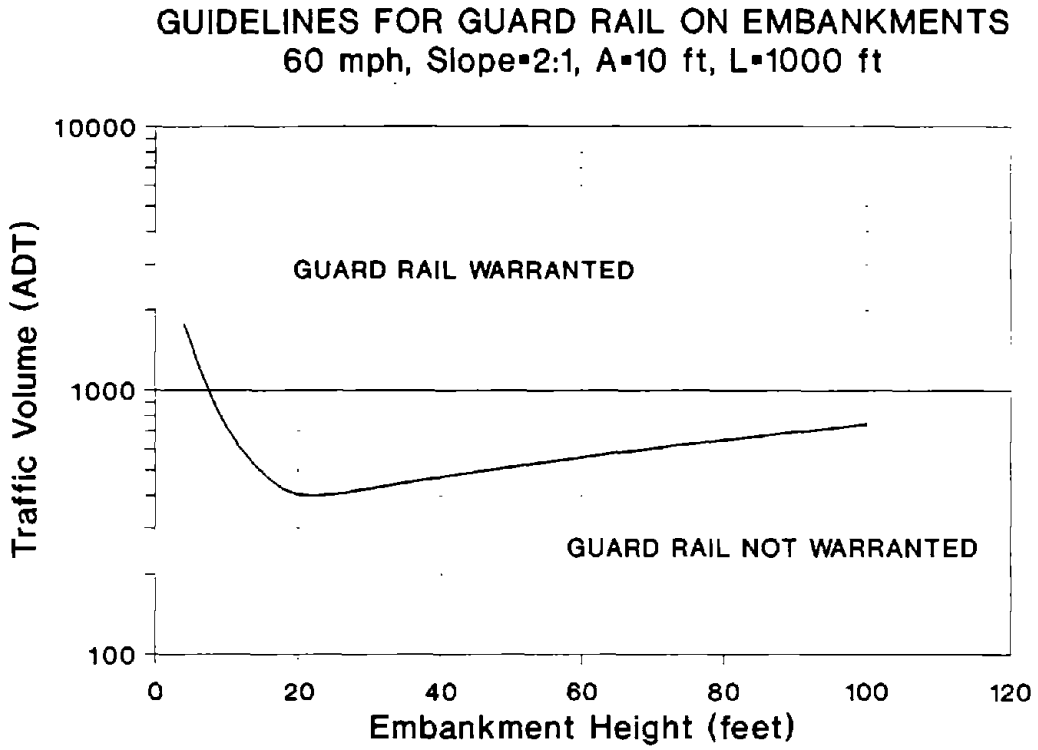

GUIDELINES FOR GUARD RAIL ON EMBANKMENTS
60 mph, Slope=2:1, A=10 ft, L=1000 ft
10000
1000
100
Traffic Volume (ADT)
GUARD RAIL WARRANTED
GUARD RAIL NOT WARRANTED
0
20
40
60
80
100
120
Embankment Height (feet)

FIGURE 24.

Bridge Ends and Guard Rail at Bridge Ends

1. For design speeds of 40, 50, and 60 mph, guard rail installations at bridge ends were found to be economically justified at differing traffic volume thresholds for all roadway conditions investigated. The elevation of the embankment upon which the guard rail would be placed was standardized at 20 feet for this evaluation. As shown in Table 37, the ADT levels where the guard rail becomes economically justified are rather low at the 60 mph design speed. The ADT threshold for guard rail increases as the lateral offset increases. Also, the ADT threshold for guard rail decreases noticeably as the design speed increases.

2. The use of 11 feet or 12 feet for the paved lane width did not affect the ADT threshold results by a substantial amount. For instance, as Table 37 shows, at 50 mph with lateral offset equal to 8 feet, the ADT level justifying guard rail with lane width equal to 11 feet is 910 vehicles per day; while the corresponding value with lane width equal to 12 feet is 931 vehicles per day. Such a small difference would be very difficult to estimate for a specific roadway, and it would seem appropriate to use the ADT values obtained by the analysis with paved lane width of 11 feet.

TABLE 37.

BRIDGE END vs. BRIDGE END WITH GUARDRAIL: ADT GUIDELINES FOR GUARD RAIL INSTALLATION FOR 11 FT AND 12 FT DRIVING LANE WIDTHS

Width of Paved Driving Lane, (ft)	Lateral Offset from Driving Lane Edge to Bridge End, (ft)	Average Daily Traffic (ADT)* Design Speed (mph)		
		40	50	60
11	2	1876	663	417
12	2	1927	679	426
11	8	3276	910	475
12	8	3356	931	486
11	10	3981	948	492
12	10	4077	969	502

* Break-even ADT for bridge end vs. bridge end with guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

RECOMMENDATIONS

The following recommendations are presented to the MHTD concerning guard rail installation on embankments and at bridge ends on two-lane low-volume highways. The recommendations are based on results obtained by application of the AASHTO ROADSIDE computer program.

1. It is not necessary to develop separate guidelines for paved lane widths of both 11 feet and 12 feet for the traffic and roadside conditions that were evaluated in this study. It is recommended that results from an analysis with a paved lane of 11 feet be used for both paved lane widths, unless it is known that all lanes on all low-volume roads will be 12 feet wide.

2. Results of the analyses for guard rail installation on roads with a 40 mph design speed indicated that guard rail is not economically justified on embankments with either 3:1 or 2:1 cross slope at that low of a design speed. It must be noted that for a specific roadway the operating speed and/or posted speed might be greater than the design speed. In those instances, the results listed for the 40 mph analyses might not be appropriate.

3. Results of the analyses for guard rail installation on roads with a 50 or 60 mph design speed indicated that guard rail is not economically justified on embankments with 3:1 cross slope. However, embankments with a 2:1 cross slope should have guard rail installed in almost all situations. Tables and graphs are provided in this report showing the conditions under which guard rail should be installed. It must be noted that for a specific roadway the operating speed and/or operating speed might be greater than the design speed. In those instances, the results listed for the 50 mph analyses might not be appropriate.

4. Results of the analyses for guard rail installation on 2:1 embankments at 50 mph and 60 mph design speeds should be adjusted to avoid the difficulty of having the break-even ADT increase for embankment heights exceeding 20 feet. It is suggested that the break-even ADT for the embankment height of 20 feet could be used if an embankment is in excess of that height.

5. The four recommendations listed above concerning guard rail placement on embankments are based on analyses which assumed absence of any specific hazardous object on the embankment or at the bottom of the embankment. If any hazardous object is identified as being present along or at the bottom of a actual embankment, a special guard rail evaluation should be conducted using the ROADSIDE program.

6. Results of the analyses for guard rail installation at bridge ends yielded break-even ADT levels that could serve directly as guidelines for the installation of guard rail on 40, 50, and 60 mph design speed roads. However, these ADT levels have been rounded off to more convenient numbers that could be applied to actual situations. These recommended ADT levels for guard rail at bridge ends are in Table 38.

TABLE 38.

PROPOSED GUIDELINES FOR ADT LEVELS WARRANTING GUARD RAIL INSTALLATION AT BRIDGE ENDS

Lateral Offset from Driving Lane Edge to Bridge End, (ft)	Average Daily Traffic (ADT)* Design Speed (mph)		
	40**	50**	60
2	1870	650	400
8	3270	900	470
10	3980	940	490

* Break-even ADT for bridge end vs. bridge end with guard rail; locations with traffic exceeding listed ADT should have guard rail installed.

** It must be regonized that the break-even ADT's at 40 mph and 50 mph might have to be adjusted due to the possibility of the operating speed or posted speed exceeding the design speed.

7. It is recommended that the MHTD proceed at the earliest possible date to implement the findings of this study. Also, it is recommended that MHTD consider additional investigations using the ROADSIDE computer program to evaluate the influence of horizontal curves and grades on the need for guard rail at embankments.

8. This study has indicated that vehicles on roads with an especially low ADT evidently do not have a sufficient number of collisions with bridge ends to justify installing the standard guard rail components. This finding raises two important questions; namely:

   A. Is the encroachment model appropriate for conditions where drivers are approaching bridge ends?

   B. Should some type of protective device other than guard rail be installed just prior to a bridge end to offer some distance for decelerating the vehicle before it encounters the bridge end?

REFERENCES

1. American Association of State Highway and Transportation Officials, "Roadside Design Guide," 1989.

2. Missouri Highway and Transportation Department, Policy Procedure and Design Manual, correspondence dated April 1, 1991.

3. Glennon, J.C., and C. J. Wilton, "Effectiveness of Roadside Improvements, Volume 1., A Methodology for Determining the Effectiveness of Improvements on All Classes Highways," Report No. FHWA-RD-75-23, Office of Research and Development, Federal Highway Administration, November, 1974.

4. Federal Highway Administration, "Supplemental Information for Use with the ROADSIDE Computer Program, (advance copy), June 1991.

APPENDIX A

DEVELOPMENT OF ACCIDENT COSTS FOR USE IN ROADSIDE

Accident costs used in the ROADSIDE computer program had to be established according to six levels of severity. These levels of severity and the default accident cost values provided in the AASHTO "Roadside Design Guide" are shown in Table A-1:

TABLE A-1.

ROADSIDE DESIGN GUIDE DEFAULT ACCIDENT COSTS

Accident Severity	Cost ($)
Fatality	500,000
Severe Personal Injury	110,000
Moderate Personal Injury	10,000
Slight Personal Injury	3,000
Property Damage Only (Level 2)*	2,500
Property Damage Only (Level 1)**	500

*Property Damage Only (Level 2) category contains 9.6 percent injury accidents.
**Property Damage Only (Level 1) category contains no injury accidents.

Traffic safety project analyses currently performed at the MHTD utilize the three levels of accident severity and costs listed in Table A-2.

TABLE A-2.

MHTD ACCIDENT COSTS

Accident Severity	Cost ($)
Fatality	1,900,000
Injury	21,100
Property Damage Only	4,000

Clearly, the two sets of accident costs are not compatible in terms of severity level definitions or the range of costs. In order to generate a set of six accident cost levels for input to the ROADSIDE computer program it was necessary to develop a linearly proportional relationship between the two sets of costs. The relationship was based on the two extreme points, namely: the costs for a property damage only accident and the costs

for a fatality accident. The four intermediate levels of injury accident costs were then calculated by linear interpolation. The interpolation procedure that was used is described by the following equation:

$$Y = 4{,}000 + \left[\frac{1{,}900{,}000 - 4{,}000}{500{,}000 - 500}\right] (X)$$

where: Y is the adjusted value for input to the ROADSIDE computer program, and

X is the default value from the AASHTO "Roadside Design Guide"

The values that were obtained from the linearly proportional relationship and the rounded off values actually used in the ROADSIDE program are listed in Table A-3.

TABLE A-3.

ACCIDENT COSTS FOR INPUT TO THE ROADSIDE PROGRAM

Accident Severity Level	Computed Cost ($)	Cost ($) Used in ROADSIDE Program
Fatality	1,900,000	1,900,000
Severe Injury	419,640	419,640
Moderate Injury	40,060	40,060
Slight Injury	13,489	13,490
Property Damage Only (Level 2)	11,591	11,590
Property Damage Only (Level 1)	4,000	4,000