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# Upgrading of Bridge Approach Guardrail on Primary Roads In Iowa

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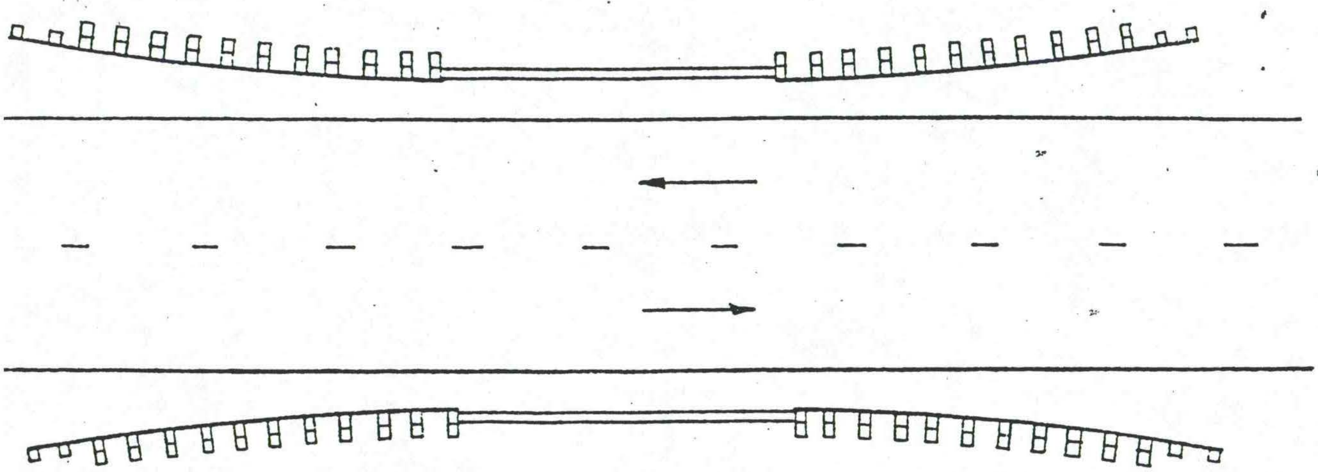
# UPGRADING OF BRIDGE APPROACH GUARDRAIL

# ON

# PRIMARY ROADS IN IOWA



BY

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June 14, 1989

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## INTRODUCTION

Bridge approach guardrail is used at the ends of bridge rail to prevent dangerous end impacts. Approximately 65 percent of Iowa's bridge accident fatalities are due to end impacts with unprotected bridge rail. Vehicles striking rigid rail ends come to an almost immediate stop. This large change in velocity puts tremendous forces on the occupants causing the high fatality rates. In Iowa, from 1977 to 1989, there were 2,333 accidents involving bridges on Primary roads which resulted in 68 deaths and 881 injuries. The total value loss for this 11-year period is estimated at $54.5 million. This is calculated using figures of $435,000 for each fatal accident, $15,000 for each injury accident, and $900 (or the actual amount if known) for property damage only accidents.

The purpose of this report is to examine the accident data at bridges on Iowa's Primary system and the cost effectiveness of installing approach guardrail in order to justify a program to upgrade approach guardrail at bridges on Iowa's Primary system. It is generally accepted that approach guardrail should be used at bridge ends to reduce the number of end impacts and it is installed at all newly constructed bridges and at bridges that have deck overlays or other work. However, about 1,600 of the 3,849 bridges on the Primary System have substandard or no approach guardrail. Thus an attempt should be made to reduce the hazard of unprotected bridge railing and substandard approach guardrail.

## BRIDGE ACCIDENT SEVERITY

The average accident severity is a number used to describe the severity of a sample of accident data. The following is the severity index used in Iowa:

| | |
|---|---|
| Fatal Accident | = 12 |
| Injury Accident | = 3 |
| Property Damage Only | = 1 |

These factors are used in the following formula to calculate the average accident severity:

$$S=\frac{12F+3I+PDO}{N}$$

Where: S = Average accident severity
F = Number of fatal accidents
I = Number of injury accidents
PDO = Number of property damage only accidents

This number is a weighted average making it very useful for comparing the accident severity of different groups of data.

The number of accidents at Iowa bridges on Primary roads has been declining since 1977, which can be seen in Figure 1. We would expect that the average severity of bridge accidents would also decline during this period since approach guardrail was added to many bridges. The data in Table 1 shows that the overall average accident severity for bridge accidents from 1977-1987 is 2.04. This number is not an average of the yearly severity number. It was calculated using the above formula for all the data. Looking at all the data it is difficult to determine if the average severity has been declining during this period. However, if we break the data down into two groups, as in Table 2, we see that the average severity for the years 1982-1987 is lower than that for the period of 1977-1981. Or, if we consider the five-year periods of 1978-1982 and 1983-1987, as shown in Table 3, we still get a difference in average severity of 0.05. Note that this would exclude the extreme high of 2.30 in 1977.

It should be noted that these severity numbers represent all types of bridge accidents including rail impacts and approach guardrail impacts which are lower in severity. If the data could be broken down into impact type, we would expect the severity of end impacts of unshielded bridge rail to be much higher than the overall severity.

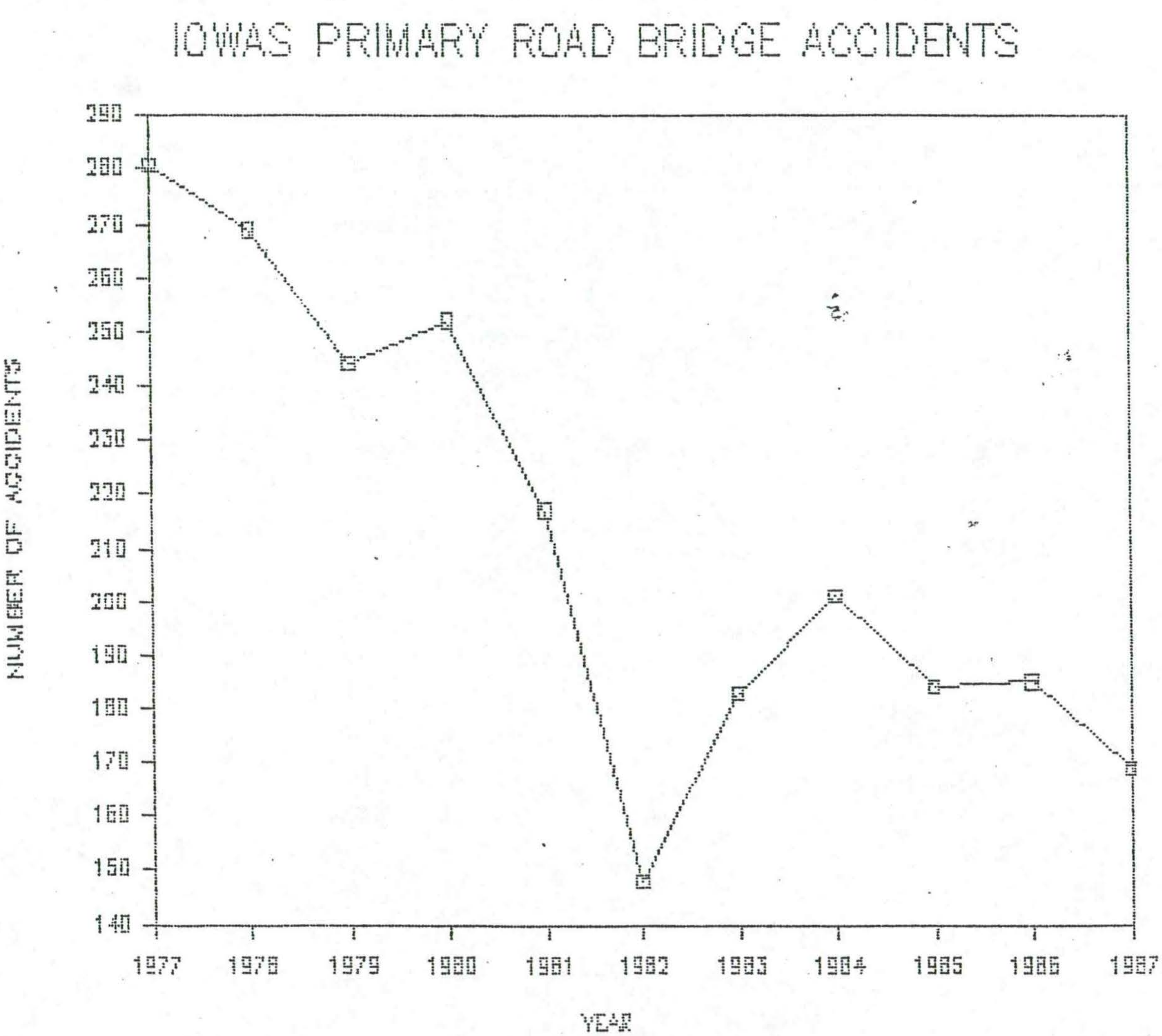

IOWAS PRIMARY ROAD BRIDGE ACCIDENTS
NUMBER OF ACCIDENTS
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
YEAR

**Figure 1**

PRIMARY ROAD BRIDGE ACCIDENTS IN IOWA

| YEAR | # OF ACC | FATAL | INJURY | PDO | KILLED | INJURED | $ LOSS | AVG. $ LOSS | TOTAL SEVERITY | AVG SEVERITY |
|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 169 | 5 | 62 | 102 | 5 | 77 | 3,992,130 | 23,622.07 | 348 | 2.06 |
| 1986 | 185 | 3 | 70 | 112 | 3 | 99 | 3,404,990 | 18,405.35 | 358 | 1.94 |
| 1985 | 184 | 2 | 72 | 110 | 4 | 104 | 3,949,650 | 21,465.49 | 350 | 1.90 |
| 1984 | 201 | 7 | 72 | 122 | 7 | 92 | 4,945,190 | 24,602.94 | 422 | 2.10 |
| 1983 | 183 | 5 | 57 | 121 | 5 | 77 | 3,853,190 | 21,055.68 | 352 | 1.92 |
| 1982 | 148 | 3 | 55 | 90 | 3 | 75 | 3,060,480 | 20,678.92 | 291 | 1.97 |
| 1981 | 217 | 6 | 75 | 136 | 8 | 110 | 5,856,400 | 26,988.02 | 433 | 2.00 |
| 1980 | 252 | 8 | 96 | 148 | 8 | 133 | 6,093,730 | 24,181.47 | 532 | 2.11 |
| 1979 | 244 | 3 | 103 | 138 | 3 | 128 | 3,889,410 | 15,940.20 | 483 | 1.98 |
| 1978 | 269 | 9 | 92 | 168 | 12 | 128 | 7,833,890 | 29,122.27 | 552 | 2.05 |
| 1977 | 281 | 10 | 127 | 144 | 10 | 187 | 7,664,340 | 27,275.23 | 645 | 2.30 |
| TOTALS | 2,333 | 61 | 881 | 1,391 | 68 | 1,210 | 54,543,400 | 23,379.08 | 4,766 | 2.04 |

Table 1

PRIMARY ROAD BRIDGE ACCIDENTS IN IOWA

| YEAR | # OF ACC | FATAL | INJURY | PDO | KILLED | INJURED | $ LOSS | AVG. $ LOSS | TOTAL SEVERITY | AVG SEVERITY |
|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 169 | 5 | 62 | 102 | 5 | 77 | 3,992,130 | 23,622.07 | 348 | 2.06 |
| 1986 | 185 | 3 | 70 | 112 | 3 | 99 | 3,404,990 | 18,405.35 | 358 | 1.94 |
| 1985 | 184 | 2 | 72 | 110 | 4 | 104 | 3,949,650 | 21,465.49 | 350 | 1.90 |
| 1984 | 201 | 7 | 72 | 122 | 7 | 92 | 4,945,190 | 24,602.94 | 422 | 2.10 |
| 1983 | 183 | 5 | 57 | 121 | 5 | 77 | 3,853,190 | 21,055.68 | 352 | 1.92 |
| 1982 | 148 | 3 | 55 | 90 | 3 | 75 | 3,060,480 | 20,678.92 | 291 | 1.97 |
| TOTALS | 1070 | 25 | 388 | 657 | 27 | 524 | $23,205,630 | $21,687.50 | 2121 | 1.98 |
| | | | | | | | | | | |
| 1981 | 217 | 6 | 75 | 136 | 8 | 110 | 5,856,400 | 26,988.02 | 433 | 2.00 |
| 1980 | 252 | 8 | 96 | 148 | 8 | 133 | 6,093,730 | 24,181.47 | 532 | 2.11 |
| 1979 | 244 | 3 | 103 | 138 | 3 | 128 | 3,889,410 | 15,940.20 | 483 | 1.98 |
| 1978 | 269 | 9 | 92 | 168 | 12 | 128 | 7,833,890 | 29,122.27 | 552 | 2.05 |
| 1977 | 281 | 10 | 127 | 144 | 10 | 187 | 7,664,340 | 27,275.23 | 645 | 2.30 |
| TOTALS | 1263 | 36 | 493 | 734 | 41 | 686 | $31,337,770 | $24,812.17 | 2645 | 2.09 |

Table 2

PRIMARY ROAD BRIDGE ACCIDENTS IN IOWA

| YEAR | # OF ACC | FATAL | INJURY | PDO | KILLED | INJURED | $ LOSS | AVG. $ LOSS | TOTAL SEVERITY | AVG SEVERITY |
|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 169 | 5 | 62 | 102 | 5 | 77 | 3,992,130 | 23,622.07 | 348 | 2.06 |
| 1986 | 185 | 3 | 70 | 112 | 3 | 99 | 3,404,990 | 18,405.35 | 358 | 1.94 |
| 1985 | 184 | 2 | 72 | 110 | 4 | 104 | 3,949,650 | 21,465.49 | 350 | 1.90 |
| 1984 | 201 | 7 | 72 | 122 | 7 | 92 | 4,945,190 | 24,602.94 | 422 | 2.10 |
| 1983 | 183 | 5 | 57 | 121 | 5 | 77 | 3,853,190 | 21,055.68 | 352 | 1.92 |
| TOTALS | 922 | 22 | 333 | 567 | 24 | 449 | $20,145,150 | $21,849.40 | 1830 | 1.98 |
| | | | | | | | | | | |
| 1982 | 148 | 3 | 55 | 90 | 3 | 75 | 3,060,480 | 20,678.92 | 291 | 1.97 |
| 1981 | 217 | 6 | 75 | 136 | 8 | 110 | 5,856,400 | 26,988.02 | 433 | 2.00 |
| 1980 | 252 | 8 | 96 | 148 | 8 | 133 | 6,093,730 | 24,181.47 | 532 | 2.11 |
| 1979 | 244 | 3 | 103 | 138 | 3 | 128 | 3,889,410 | 15,940.20 | 483 | 1.98 |
| 1978 | 269 | 9 | 92 | 168 | 12 | 128 | 7,833,890 | 29,122.27 | 552 | 2.05 |
| TOTALS | 1130 | 29 | 421 | 680 | 34 | 574 | $26,733,910 | $23,658.33 | 2291 | 2.03 |

Table 3

The average accident severities for fixed object accidents are shown in Table 4. These numbers were calculated from accident data taken from the report "Iowa Fixed Object Accident Analysis" by Dominic Vi-Minh Hoang, a Highway Engineer Trainee with the Iowa Division of the Federal Highway Administration. There is a slight difference between the average accident severity of bridge accidents for this data and for the data that I obtained. Therefore, the data in Table 4 will only be used to compare the severity of different fixed object accidents. Table 4 shows that bridge accidents rank sixth among fixed object accidents for overall accident severity with an average of 2.00. This number takes into account all bridge impacts, including those of shielded bridges, which account for more than half of the bridges on Iowa's primary system. Guardrail, on the other hand, ranks twelfth among fixed objects with an overall accident severity of 1.85. With this high severity number, guardrail would be considered a hazard. However, according to the <u>AASHTO Roadside Design Guide</u>, barriers should be installed if it will reduce the severity of potential accidents. Therefore, guardrail should be installed or upgraded at bridge because it will reduce the severity of accidents. It should be noted that some older substandard guardrail is still in use. This, along with improper installation of newer guardrail, will result in substandard performance of guardrail, which could account for the somewhat high average severity for guardrail.

**FATAL BRIDGE ACCIDENTS**

The Iowa Division of FHWA has received copies of all accident reports for fatal accidents at bridges and culverts in the state of Iowa since 1981. Of the 90 fatal bridge accidents studies, 61 (or 68%) involved vehicles striking the end of bridges or bridge rails that were not protected by approach guardrail. About one-third of these accidents occurred on Primary roads. It is this type of accident that accounts for the high severity for bridge accidents. Vehicles striking bridge ends almost come to an immediate stop. High injury and fatality rates are due to impacts with objects which are substantial enough to stop vehicles upon impact, thus causing high changes in velocity. Approach guardrail is more forgiving. If properly installed, it will reduce this change in velocity, which should reduce injury and fatality rates at bridges.

The <u>1977 AASHTO Guide for Selecting and Designing Traffic Barriers</u> shows that the probability of end impacts is dependent upon the length of the bridge. Of all possible impacts with the bridge rail for vehicles leaving the travelled way at an angle 0, the probability (P) of impacting the end of the rail is given by:

$$P = (2Lc \times 100\%)/(Lb\sin 0+2Lc)$$

Where: Lc = Length of the bridge
Lb = Effective width of the car
0 = Angle of encroachment
See Figure 2.

IOWA
FIXED OBJECT ACCIDENTS
AVERAGE SEVERITY*

| | | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | OVERALL SEVERITY |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Embankment/Wall | 2.83 | 2.45 | 2.95 | 2.59 | 2.58 | 2.58 | 2.33 | 2.63 |
| 2. | Culvert | 2.43 | 2.38 | 2.73 | 2.24 | 2.66 | 2.36 | 2,53 | 2.47 |
| 3. | Tree/Shrubbery | 2.11 | 2.19 | 2.42 | 2.70 | 2.31 | 2.40 | 2.20 | 2.32 |
| 4. | Ditch | 2.33 | 2.19 | 2.31 | 2.38 | 2.32 | 2.25 | 2.36 | 2.30 |
| 5. | Utility Pole | 1.98 | 2.03 | 1.95 | 2.02 | 2.07 | 2.18 | 1.93 | 2.02 |
| 6. | Bridge Overpass | 2.12 | 2.01 | 1.99 | 1.97 | 1.85 | 2.06 | 1.98 | 2.00 |
| 7. | Building | 1.92 | 2.05 | 2.00 | 1.91 | 1.73 | 1.92 | 2.29 | 1.98 |
| 8. | Isl/Raised Med | 2.03 | 1.82 | 1.94 | 2.04 | 1.91 | 1.85 | 2.22 | 1.97 |
| 9. | Curb | 2.03 | 2.03 | 1.95 | 1.91 | 1.81 | 1.95 | 2.01 | 1.96 |
| 10. | Fence | 1.90 | 1.96 | 2.02 | 2.07 | 2.05 | 1.90 | 1.83 | 1.96 |
| 11. | Light Pole | 1.84 | 1.79 | 2.01 | 1.83 | 1.92 | 1.97 | 2.00 | 1.90 |
| 12. | Gaurdrail | 1.80 | 2.09 | 1.74 | 1.97 | 1.72 | 1.85 | 1.80 | 1.85 |
| 13. | Sign Post | 1.75 | 1.82 | 1.77 | 1.93 | 2.06 | 1.88 | 1.79 | 1.85 |
| 14. | Other Pole/Sup | 1.72 | 1.74 | 1.94 | 1.91 | 2.06 | 1.99 | 1.76 | 1.85 |
| 15. | Bridge Supports | 1.55 | 1.74 | 1.50 | 1.91 | 2.31 | 1.90 | 1.67 | 1.75 |
| 16. | Mailbox | 1.41 | 1.79 | 1.39 | 1.88 | 1.86 | 1.93 | 1.39 | 1.65 |
| 17. | Imp Attenuator | 1.00 | 1.89 | 1.48 | 1.40 | 1.26 | 1.24 | 1.94 | 1.44 |

*Calculated from accident data taken from the report "Iowa Fixed Object Accident Analysis" by Dominic Vi-Minh Hoang of the Federal Highway Administration.

Table 4

Bridge
Rail
System

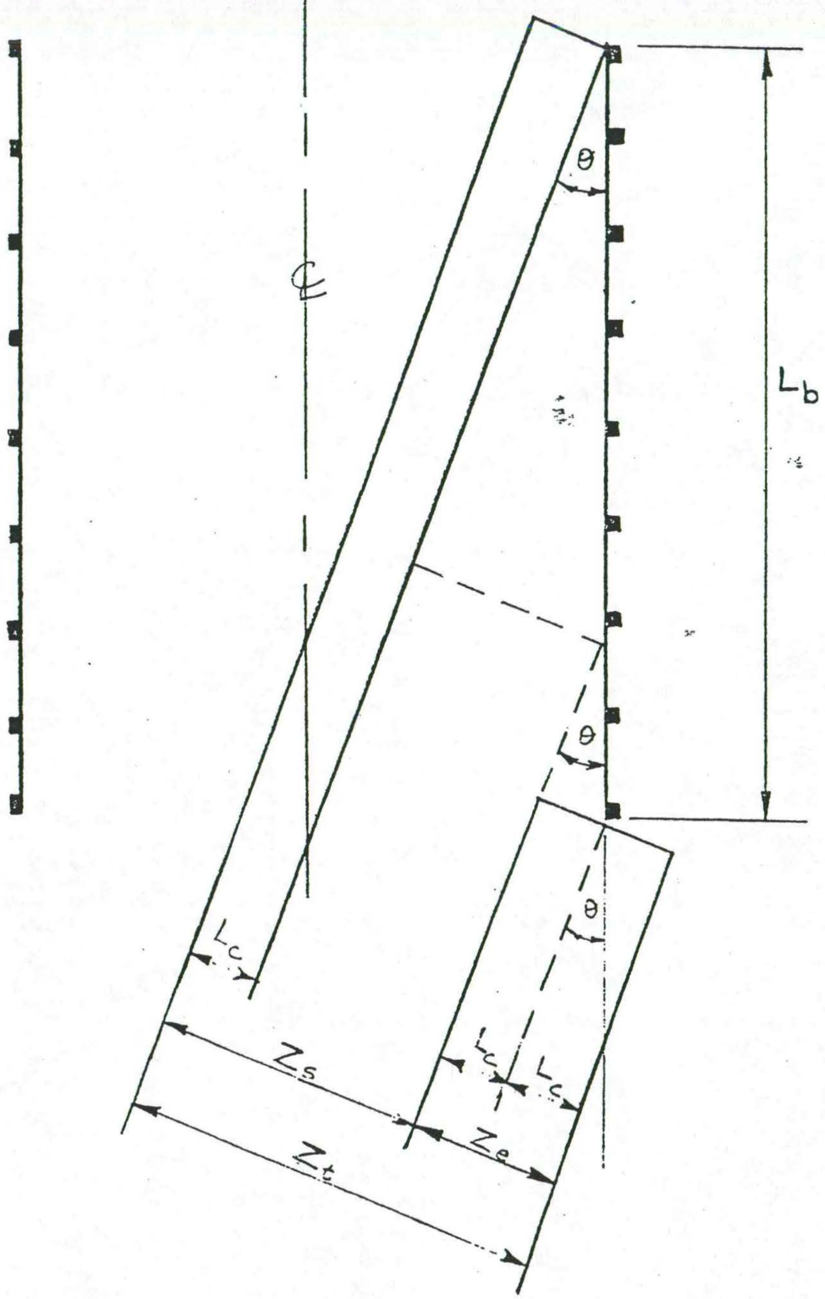



Figure 2

$Z_e = ZL_c$ = Zone in which vehicle would impact end of bridge

$Z_s$ = Zone in which vehicle would impact side of bridge rail

$Z_t$ = Zone of all vehicle impacts with bridge rail

Figure 3 shows a plot of bridge length versus percentage of end impacts for an encroachment angle of 0 = 10 degrees and Lc = 96". For a 100' bridge, we would expect 50 percent of all accidents to be end impacts. The graph shows the percentage of end impacts. Also, as the graph shows the percentage of end impacts increases as the bride length decreases. Thus, it is important to consider all bridges for approach guardrail regardless of how short the bridge may be.

## ADEQUACY OF PRIMARY BRIDGE APPROACH GUARDRAIL IN IOWA

Item 36 of the Recording and Coding Guide for the Structural Inventory and Appraisal of the Nations Bridges gives guidance for coding of traffic safety features for bridge inspections. Traffic safety features uses a 4-digit code consisting of four segments which are listed below:

| SEGMENT | DESCRIPTION | LENGTH |
|---|---|---|
| 36A | Bridge Railing | 1 Digit |
| 36B | Transitions | 1 Digit |
| 36C | Approach Guardrail | 1 Digit |
| 36D | Approach Guardrail Ends | 1 Digit |

These features are reported with the following coding:

| CODE | DESCRIPTION |
|---|---|
| 0 | Does not meet currently acceptable standards. |
| 1 | Meets currently acceptable standards. |
| N | Not applicable. |

There is no national set of standards; therefore, it is up to the inspecting authority to determine what are "currently acceptable standards."

Data obtained from the Iowa DOT lists the number of bridges that are currently up to standard and the number that are not. This is shown in Table 5. According to this data, 43 percent of approach guardrail ends, 27 percent of Approach guardrail and 33 percent of transitions are substandard. Assuming that if any portion of the approach guardrail is not up to current standards, and the entire approach system is substandard, we can assume that at least 43 percent of approach guardrail on Iowa's 3,849 primary bridges are substandard. Therefore, there could be as many as 1,600 bridges with substandard approach guardrail based on Iowa's interpretation of "currently acceptable standards."

$P=(2L_c \times 100)/(L_b \sin \theta + 2L_c)$

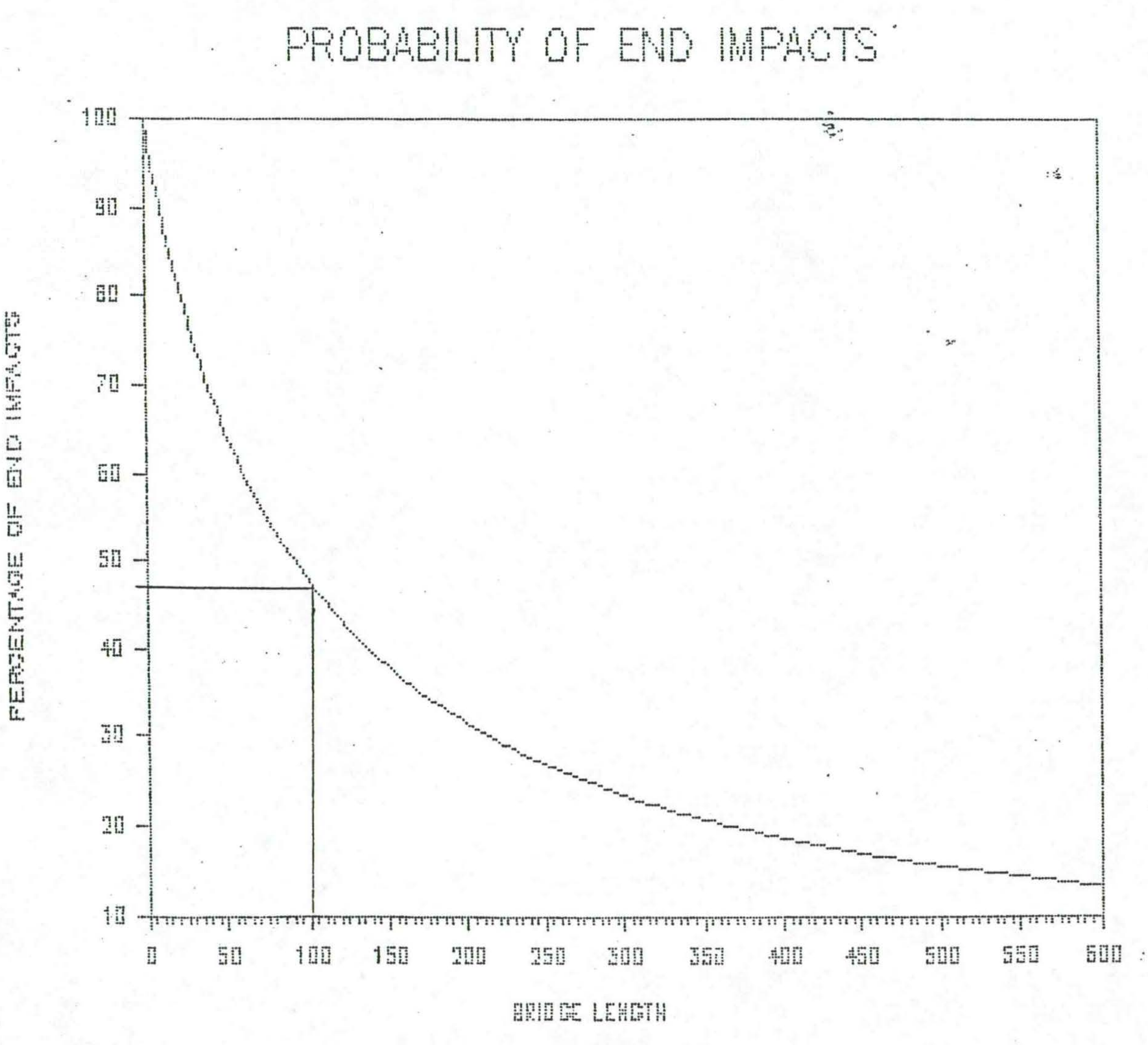



Figure 3

BRIDGE INVENTORY: TRAFFIC SAFETY FEATURES *

| | Item 36 Coded as | | |
|---|---|---|---|
| | 1 | 0 | N |
| Terminals | 2,111 | 1,670 | 68 |
| Approach Guardrail | 2,732 | 1,049 | 68 |
| Transitions | 2,531 | 1,251 | 67 |
| Bridge Handrail | 1,502 | 2,280 | 67 |

*Item 36 of Recording and Coding Guide for the Structural Inventory and Appraisal of the Nations Bridges

Table 5

Of Primary bridges, 2,280 (or 59 percent) have bridge rail that is not up to current standards. This raises a question of whether or not approach guardrail should be brought up to standard if the bridge rail is substandard. Bridge rail can be hazardous regardless of whether or not it meets current standards. Striking the end of the bridge or bridge rail is the cause of about 60-70 percent of bridge accident fatalities. It is doubtful that the severity of this type of accident is less at bridges with substandard rail. Unless a bridge with substandard guardrail is being considered for a deck overlay or some other work in the near future, at which time the guardrail and approach rail would be brought up to standard, it should be considered for upgrading of approach guardrail.

## COSTS

There are three general categories of costs associated with the upgrading of bridge approach rail that should be considered:

<u>Initial Costs</u> = Assumed by the highway department to install new approach guardrail or upgrade existing substandard approach rail.

<u>Maintenance Costs</u> = Required to maintain and repair approach barrier rail over the life of the project.

<u>Motorist Costs</u> = Resulting from impacts with the approach guardrail.

## INITIAL COSTS

Initial costs are those costs required to install the approach guardrail. Iowa currently upgrades approach guardrail in conjunction with other projects, such as overlays and reconstruction projects. When this is done, the cost of installing approach rail is usually small compared to the total cost of the project. A breakdown of costs for the different approach guardrail items from a project with typical guardrail is shown in Table 6. This table also shows the average awarded contract prices for these items from 1988. The total price for this project is higher than the 1988 awarded average, but only by about 12 percent. Therefore, $7,000 would seem to be a typical cost of upgrading approach guardrail. Because they may be considered specialty items not normally associated with another project, such as an overlay, a program to upgrade approach guardrail separately may reduce initial costs, since several locations could be included in one contract.

| Item | Low Bid for One Project: Unit Price | Low Bid for One Project: Total | 1988 Awarded Contract Prices: Unit Price | 1988 Awarded Contract Prices: Total |
|---|---|---|---|---|
| Class 10 Excavation<br>193 cu. yds.<br>109 cu. yds. | 2.03/cy | 613.06 | 1.35/cy | 407.70 |
| Guardrail, Formed Steel Beam<br>250 ft. | 8.50/ft | 2125.00 | 7.52/ft | 1880.00 |
| Guardrail, Posts, Beam<br>52 | 52.00 | 2704.00 | 42.46 | 2207.92 |
| Guardrail, End Anchorages<br>4 | 335.00 | 1340.00 | 387.23 | 1548.92 |
| | | $6782.06 | | $6044.54 |

These figures are for the current "w"-Beam approach guardrail design. The design has been changed to incorporate a nested thrie beam transition, which will slightly increase the costs of this system. However, it is not yet in use so there are no dollar figures to go by.

## MAINTENANCE COSTS

Maintenance costs can include routine maintenance, collision maintenance, and material and storage requirements. Routine maintenance includes such things as cleaning, erosion, and vegetation control. Because of the preservative-treated wood posts and galvanized steel rail components used for guardrail, the need for this type of maintenance is limited. Collision maintenance includes any needed repairs due to vehicle impacts. This would normally be a majority of maintenance costs and would depend on the number of impacts that might occur. The number of impacts would depend on several factors including traffic speed, volume, alignment, and the distance the barrier is from the road. Material and storage requirements would not be a significant cost, because approach guardrail is standardized, therefore, component parts are standardized, easy to stockpile, and readily available.

## MOTORIST COSTS

Iowa has established a value loss index to be used for economic analysis when determining cost effectiveness. The current index, shown below assigns a dollar value to accidents according to severity.

| | | |
|---|---|---|
| Fatality | | $435,000 |
| Injury | ave. | 15,000 |
| | major | 85,000 |
| | minor | 5,000 |
| | possible | 1,000 |
| Property | damage only | 900 |

These numbers were established in 1985 and may soon increase. ALAS has only one severity level for injuries and uses the weighted average of $15,000. Based on this value loss index, bridge accidents from 1977 through 1987 have accounted for $54.5 million in losses (see Table 1). This is an average of approximately $23,000 per accident. Total yearly value loss has dropped since 1981. This drop corresponds with the drop in total number of accidents. However, the average dollar loss since 1981 is still over $21,000 per accident.

## BENEFIT/COST ANALYSIS

A benefit/cost (B/C) analysis is a method used to compare estimated benefits derived from a specific action with the costs of implementing that action. For installing bridge approach guardrail, the benefit obtained is the expected reduction in accident costs at the bridge ends. These are costs associated with property damage, personal injuries, and fatalities. The costs used in this analysis are the construction and maintenance costs of the approach guardrail.

ROADSIDE is a computer program developed to compare alternate design concepts to assist the designer in making informed choices. This program follows the cost-effectiveness methodology explained in Appendix A of the AASHTO Roadside Design Guide which is an update of the 1977 AASHTO Guide for Selecting, Locating and Designing Traffic Barriers methodology. ROADSIDE was used to estimate the accident costs at bridges with and without guardrail so that B/C ratios could be determined.

The B/C ratio will vary from bridge to bridge because of varying bridge dimensions and traffic volumes. Therefore, a chart was developed to show the B/C ratios for varying traffic volumes and lateral offsets. The lateral offset being the distance the bridge is from the edge of the travelled way. This was accomplished by running the ROADSIDE program for a wide range of traffic volumes for lateral offsets of 2', 4', 6', 8' and 10'. A bridge length of 1' was used to essentially eliminate impacts along the length of the bridge rail, so that only end impacts are considered. Figure 4 shows a hazard model for adjacent traffic. The hazard is identified as a rectangle of length = L, and width = W at an offset of A from the nearest driving lane. Figure 5 shows that approach guardrail is also considered as a rectangular hazard.

When running ROADSIDE for different offsets and traffic volumes, some assumptions had to be made regarding the rest of the input data. An example of data is shown in Figures 6 and 7. The global parameters were adjusted to reflect the accident costs currently used in Iowa. Default data was used for the remainder of the global parameters. The traffic growth rate was determined from Iowa traffic data. Growth rates vary from road to road b ut overall Iowa has experienced a growth rate of about 4 percent in recent years on Primary roads. A designed speed of 60 mph was used which corresponds to an encroachment angle of 0 = 13 degrees. For analyzing bridge impacts a width of 1' and length of 1' were used. For the approach guardrail, a length of 126' was used. This is based on a typical guardrail of two, 62.5' approaches plus the 1' length of the bridge. The width used was 4'. The severity indexes for both situations were taken from a table provided in the Roadside Barrier Guide Appendix. A project life of 15 years was used which is the service life used for economic analysis of the guardrail severity reduction factor. Also, for all analysis Iowa uses an interest rate of 0 percent. The $7,000 installation cost is the cost of a typical guardrail approach with all four bridge ends protected, which was previously calculated. The repair costs were also taken from the Roadside Barrier Guide Appendix. Since this program only considers a hazard on one side of the road, the accident costs in both cases were double to account for accidents at both sides. Figure 8 shows the chart developed from the ROADSIDE Program. In Iowa, a B/C ratio of 1.2 or greater is considered good. The chart shows that traffic volumes as low as 1700 vehicles/day can have B/C of 1.2 for an offset of 2'. Ratios between 0.8 and 1.2 are in a gray area. This does not mean that bridges with these ratios should not be considered for upgrading. They should be looked into with more detail.

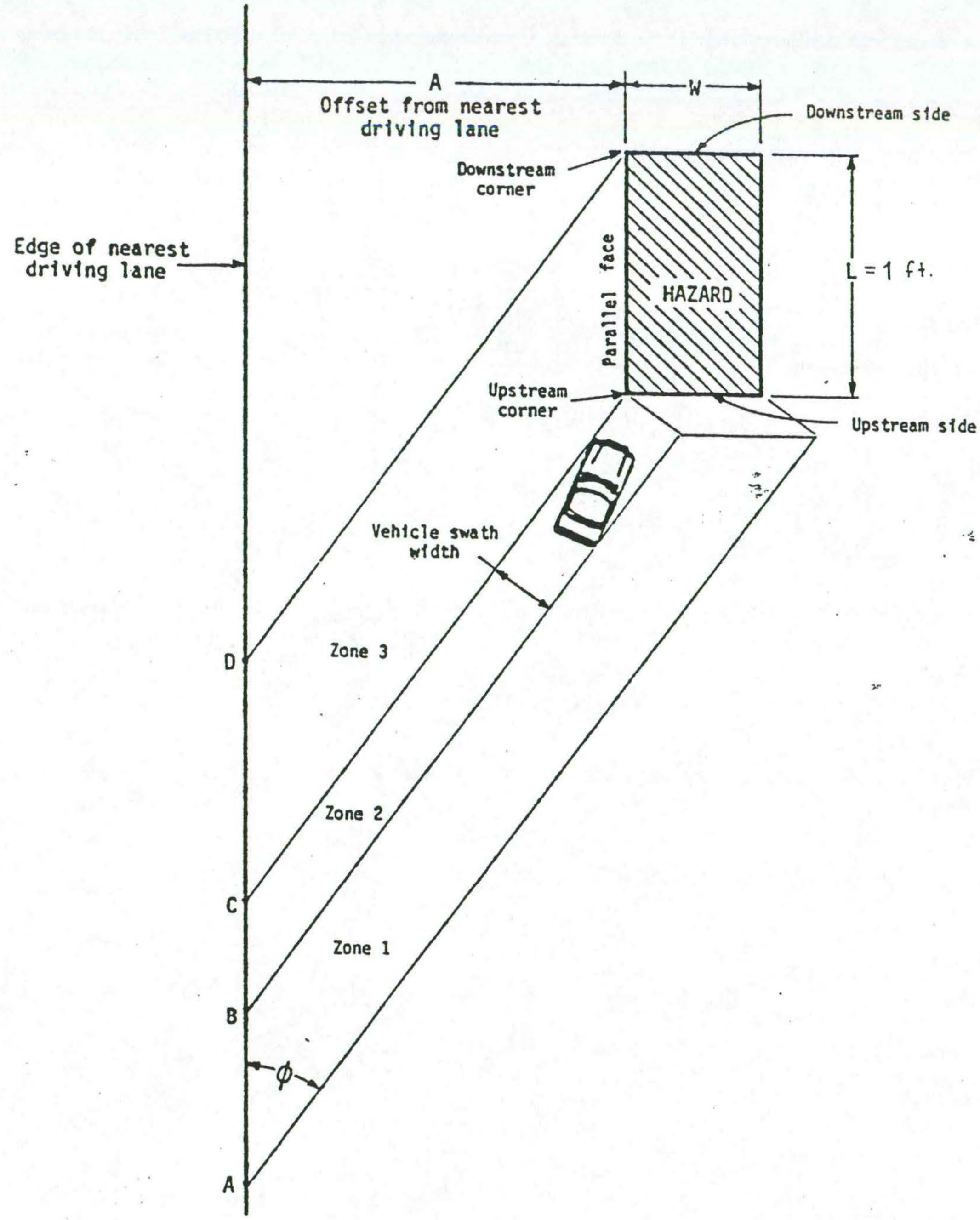

A
W
Offset from nearest driving lane
Downstream side
Downstream corner
Edge of nearest driving lane
Parallel face
HAZARD
L = 1 ft.
Upstream corner
Upstream side
Vehicle swath width
D
Zone 3
Zone 2
C
Zone 1
B
φ
A

Figure 4

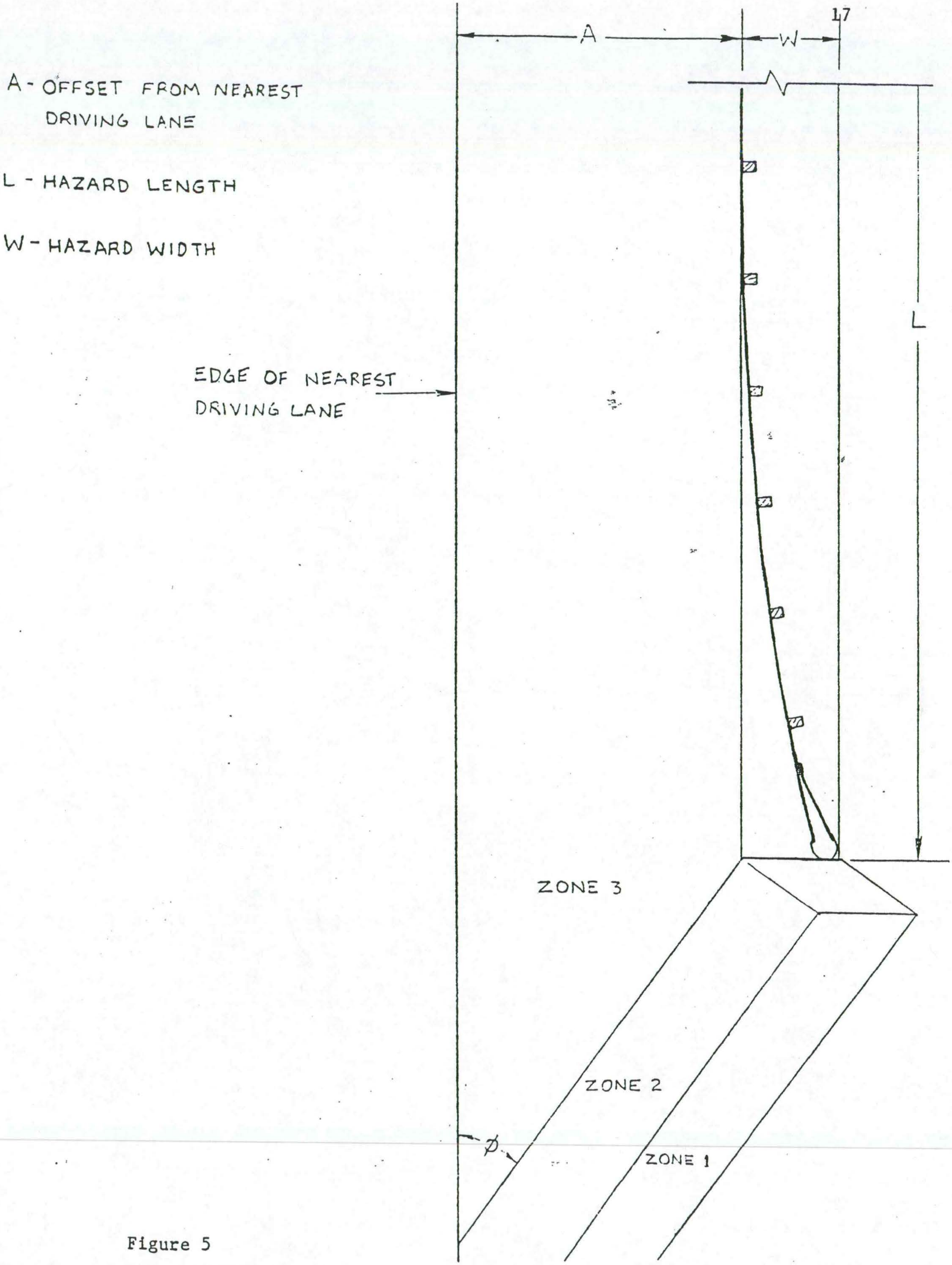

A - OFFSET FROM NEAREST DRIVING LANE
L - HAZARD LENGTH
W - HAZARD WIDTH
EDGE OF NEAREST DRIVING LANE
A
W
L
ZONE 3
ZONE 2
ZONE 1
Ø

Figure 5

GLOBAL PARAMETERS

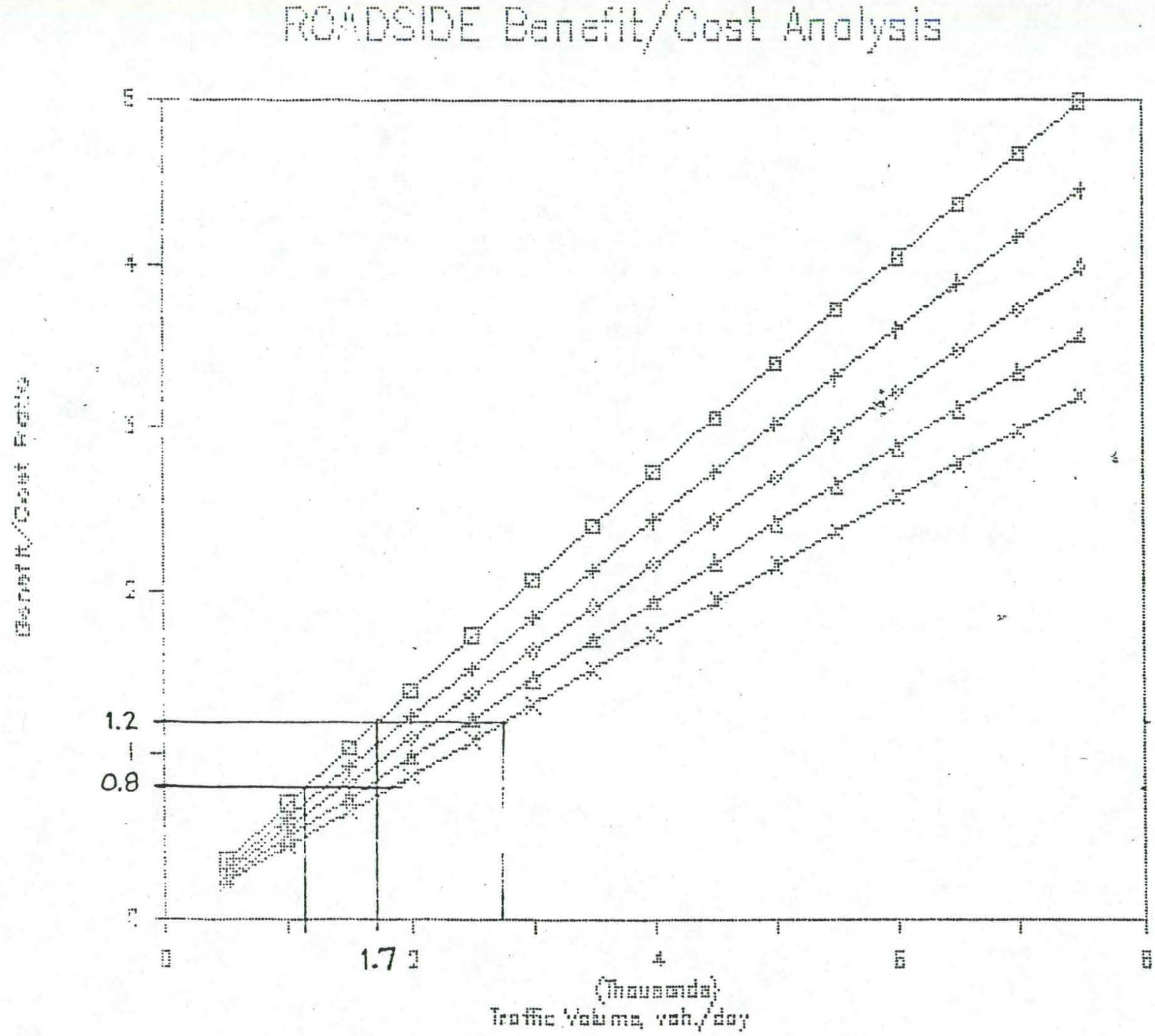
1. FATALITY COST = $ 435,000
2. SEVERE INJURY COST = $ 85,000
3. MODERATE INJURY COST = $ 5,000
4. SLIGHT INJURY COST = $ 1,000
5. PDO LEVEL 2 COST = $ 900
6. PDO LEVEL 1 COST = $ 0
7. ENCROACHMENT RATE MODEL = 0.000500 * (ADTeff ^ 1.000000 )
ENCROACHMENTS PER MILE PER YEAR
8. ENCROACHMENT ANGLE AT 40 MPH = 17.2 DEGREES
9. ENCROACHMENT ANGLE AT 50 MPH = 15.2 DEGREES
10. ENCROACHMENT ANGLE AT 60 MPH = 13.0 DEGREES
11. ENCROACHMENT ANGLE AT 70 MPH = 11.6 DEGREES
12. LIMTING TRAFFIC VOLUME PER LANE = 10,000 VEHICLES PER DAY
13. SWATH WIDTH = 12 FT.

| SEVERITY INDEX | COST |
|---|---|
| 0.0 | $ 0 |
| 0.5 | $ 0 |
| 1.0 | $ 401 |
| 2.0 | $ 1,209 |
| 3.0 | $ 6,977 |
| 4.0 | $ 19,470 |
| 5.0 | $ 45,905 |
| 6.0 | $ 97,473 |
| 7.0 | $157,518 |
| 8.0 | $241,440 |
| 9.0 | $341,900 |
| 10.0 | $435,000 |

Figure 6

```
TLE:    APPROACH GUARDRAIL

ITIAL TRAFFIC VOLUME =   1,000 VEHICLES PER DAY
AFFIC GROWTH RATE =  4.0 % PER YEAR    DESIGN YEAR ADT =    1,801
MITING TRAFFIC VOLUME PER LANE  =   10,000

DIVIDED HIGHWAY  LANE(S) OF ADJACENT TRAFFIC =   1.  LANE WIDTH = 12.0 FT.

RVATURE =   0.0 DEGREES          GRADE (PERCENTAGE) =   0.0

ITIAL ENCROACHMENT FREQUENCY = 0.0005000 * (TVeff ^ 1.000000)
        TRAFFIC   BASELINE   CURVATURE   GRADE    USER    TOTAL
        VOLUME      ENC.      FACTOR    FACTOR   FACTOR    ENC.
JACENT     500     0.2500      1.00      1.00     1.0     0.2500
POSING     500     0.2500      1.00      1.00     1.0     0.2500

SIGN SPEED = 60 MPH   ENCROACHMENT ANGLE =  13.0  SWATH WIDTH =  12.0

TERAL PLACEMENT (A)    =         2. FT.
NGITUDINAL LENGTH (L) =       126. FT.
DTH OF OBSTACLE        =         4. FT.
              ZONE1          ZONE2          ZONE3
JACENT       0.0008         0.0025         0.0060   ENCROACHMENTS/YEAR
POSING       0.0008         0.0025         0.0060   ENCROACHMENTS/YEAR

ITIAL COLLISION FREQUENCY =        0.010 IMPACTS PER YEAR
PECTED IMPACTS OVER PROJECT LIFE =       0.198
JACENT      CFT=  0.0067  CF1 =  0.0003  CF2 =  0.0014  CF3 =  0.0050
POSING      CFT=  0.0030  CF4 =  0.0001  CF5 =  0.0007  CF6 =  0.0022

EVERITY INDEX =    3.00          3.00         3.00          3.00          2.70
                  SIDEUP       SIDEDOWN    UP CORNER   DOWN CORNER       FACE
CCIDENT COST = $    6,977  $    6,977  $    6,977  $    6,977    $    5,247
NITIAL COST/YEAR IMPACTS WITH  UPSTREAM SIDE        OF HAZARD = $           2
NITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM SIDE      OF HAZARD = $           1
NITIAL COST/YEAR IMPACTS WITH  UPSTREAM CORNER      OF HAZARD = $          10
NITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM CORNER    OF HAZARD = $           5
NITIAL COST/YEAR IMPACTS WITH  FACE                 OF HAZARD = $          37
                                  TOTAL INITIAL ACCIDENT COST = $          55.

ROJECT LIFE =  15 YEARS        DISCOUNT RATE =  0.0 %
T =   15.000   KJ =    1.000     CRF =   0.067    KC  =  20.420

OST OF INSTALLATION             = $      7,000.
OST OF REPAIR  $ SU=     500  SD=      500   CU=     500   CD=     500   F=     200

AINTENANCE COST PER YEAR        = $         0.
ALVAGE VALUE                    = $         0.

OTAL PRESENT WORTH              = $      8,183.    ANNUALIZED $        546.
IGHWAY DEPARTMENT COST          = $      7,055.    ANNUALIZED $        470.

NSTALLATION COST =                $      7,000.    ANNUALIZED $        467.
EPAIR COST       =                $         55.    ANNUALIZED $          4.
AINTENANCE COST  =                $          0.    ANNUALIZED $          0.
ALVAGE VALUE     =                $          0.    ANNUALIZED $          0.
CCIDENT COST     =                $      1,128.    ANNUALIZED $         75.
```

Figure 7




Lateral Offset = 2 feet
Lateral Offset = 4 feet
Lateral Offset = 6 feet
Lateral Offset = 8 feet
Lateral Offset = 10 feet

Figure 8

## EFFECTIVENESS OF UPGRADING BRIDGE APPROACH GUARDRAIL

It is generally accepted that bridge ends should be shielded with approach guardrail to reduce the number of end impacts. However, it is difficult to determine how effective approach guardrail is in reducing the severity of bridge accidents. In Iowa, very few bridges have more than one or two accidents, so before and after statistics are impractical to look at for individual bridges. Consider, for example, that from 1977 to 1987 there were 2,333 Primary bridge accidents in Iowa, but there are 3,849 bridges on the Primary system. Therefore, on the average, there has been less than one accident per bridge over an eleven year period. As discussed earlier, if we break the data down into groups of several years, we do see a reduction of overall severity; but since this data contains all types of impacts it is not an accurate method of determining the effectiveness of approach guardrail. If the accident data could be broken down into accidents at bridges with standard approach guardrail and accidents at bridges with substandard approach guardrail, the effectiveness of approach rail would be easy to see. We would expect this to show a substantial difference in overall severity. This, however, would be a long and arduous task and because of time constraints, was not attempted. However, it may be something that should be looked into in the future, so that accident reduction factors in Iowa might be determined.

## ACCIDENT REDUCTION FACTORS

Many states have performed studies related to benefits associated with safety improvements. The Kentucky Transportation Research Program has compiled information from these studies for a list of accident reduction factors for various highway safety improvements. Reduction factors for guardrail at bridge ends varied from 10 percent to 61 percent in total accident reductions. Iowa has not performed its own study but has adopted a total accident reduction factor of 24 percent for bridge guardrail from a FHWA memorandum, Accident Reduction Levels Which May Be Attainable from Various Safety Improvements. With an average dollar loss of about $23,000 per accident, a 24% reduction would amount to $5,520 in expected benefits per accident.

## CRASH TESTING

All approach guardrail designs are crash tested before they are used in the field. This is done to be sure that they meet current standards. Crash testing allows researchers to observe how these designs might perform in the field. They make sure that cars are contained and smoothly redirected to avoid vehicular pocketing, snagging or penetration.

## PROGRAM STRATEGY

Iowa's bridge inventory shows that about 1,600 bridges have substandard approach guardrail. Because of the high benefit/cost ratios associated with upgrading of bridge approach guardrail, a large portion of these bridges will have sufficient cost effectiveness to justify upgrading. However, 1,600 bridges cannot be upgraded all at once. Therefore, there must be a selection process to determine which bridges will be upgraded. Bridges that are being considered for deck overlays or other work should not be considered for upgrading of approach guardrail since this would be done in conjunction with this type of work.

The number of bridge approach rails to be upgraded will depend upon the amount of money that will go into this program. Once this amount is determined, the number of bridge to be upgraded can be determined based on the installation cost.

There are several criteria for selecting bridges for approach rail upgrade including traffic volume, geographical proximity, lateral offset of bridge rail from the edge of the lane, accident history, and cost effectiveness. It may be best to incorporate all of these criteria into the selection process. It may be a good idea to start with accident history. There will be just a small number of bridges with an accident history. Accident history would be considered when there are several accidents at one bridge. Once the bridges with accident histories are taken care of, then another criteria would be used.

Since the cost effectiveness of bridge approach guardrail upgrading is mainly based on traffic volume and lateral offsets, it may be best to make selections based on the benefit/cost ratios. Thus using cost effectiveness as a criteria automatically incorporates traffic volume and lateral offsets.

Regardless of the criteria used, the selection process should prioritize the substandard bridges so that the upgrading of approach guardrail will have the greatest impact on bridge accident severity reduction.

# APPENDIX

## Roadside/Benefit Cost Analysis

LATERAL PLACEMENT = 1 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1930 | 610 | 7030 | 0.38 |
| 1000 | 3860 | 1220 | 7060 | 0.75 |
| 1500 | 5790 | 1830 | 7090 | 1.12 |
| 2000 | 7720 | 2440 | 7120 | 1.48 |
| 2500 | 9650 | 3050 | 7150 | 1.85 |
| 3000 | 11580 | 3660 | 7180 | 2.21 |
| 3500 | 13510 | 4270 | 7210 | 2.56 |
| 4000 | 15440 | 4880 | 7240 | 2.92 |
| 4500 | 17370 | 5490 | 7270 | 3.27 |
| 5000 | 19300 | 6100 | 7300 | 3.62 |
| 5500 | 21230 | 6710 | 7330 | 3.96 |
| 6000 | 23160 | 7320 | 7360 | 4.30 |
| 6500 | 25090 | 7930 | 7390 | 4.64 |
| 7000 | 27020 | 8540 | 7420 | 4.98 |
| 7500 | 28950 | 9150 | 7450 | 5.32 |

LATERAL PLACEMENT = 2 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1800 | 564 | 7028 | 0.35 |
| 1000 | 3600 | 1128 | 7056 | 0.70 |
| 1500 | 5400 | 1692 | 7084 | 1.05 |
| 2000 | 7200 | 2256 | 7112 | 1.39 |
| 2500 | 9000 | 2820 | 7140 | 1.73 |
| 3000 | 10800 | 3384 | 7168 | 2.07 |
| 3500 | 12600 | 3948 | 7196 | 2.40 |
| 4000 | 14400 | 4512 | 7224 | 2.74 |
| 4500 | 16200 | 5076 | 7252 | 3.07 |
| 5000 | 18000 | 5640 | 7280 | 3.40 |
| 5500 | 19800 | 6204 | 7308 | 3.72 |
| 6000 | 21600 | 6768 | 7336 | 4.04 |
| 6500 | 23400 | 7332 | 7364 | 4.36 |
| 7000 | 25200 | 7896 | 7392 | 4.68 |
| 7500 | 27000 | 8460 | 7420 | 5.00 |

LATERAL PLACEMENT = 3 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1683 | 523 | 7026 | 0.33 |
| 1000 | 3366 | 1046 | 7052 | 0.66 |
| 1500 | 5049 | 1569 | 7078 | 0.98 |
| 2000 | 6732 | 2092 | 7104 | 1.31 |
| 2500 | 8415 | 2615 | 7130 | 1.63 |
| 3000 | 10098 | 3138 | 7156 | 1.95 |
| 3500 | 11781 | 3661 | 7182 | 2.26 |
| 4000 | 13464 | 4184 | 7208 | 2.57 |
| 4500 | 15147 | 4707 | 7234 | 2.89 |
| 5000 | 16830 | 5230 | 7260 | 3.20 |
| 5500 | 18513 | 5753 | 7286 | 3.50 |
| 6000 | 20196 | 6276 | 7312 | 3.81 |
| 6500 | 21879 | 6799 | 7338 | 4.11 |
| 7000 | 23562 | 7322 | 7364 | 4.41 |
| 7500 | 25245 | 7845 | 7390 | 4.71 |

LATERAL PLACEMENT = 4 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1577 | 484 | 7024 | 0.31 |
| 1000 | 3154 | 968 | 7048 | 0.62 |
| 1500 | 4731 | 1452 | 7072 | 0.93 |
| 2000 | 6308 | 1936 | 7096 | 1.23 |
| 2500 | 7885 | 2420 | 7120 | 1.54 |
| 3000 | 9462 | 2904 | 7144 | 1.84 |
| 3500 | 11039 | 3388 | 7168 | 2.13 |
| 4000 | 12616 | 3872 | 7192 | 2.43 |
| 4500 | 14193 | 4356 | 7216 | 2.73 |
| 5000 | 15770 | 4840 | 7240 | 3.02 |
| 5500 | 17347 | 5324 | 7264 | 3.31 |
| 6000 | 18924 | 5808 | 7288 | 3.60 |
| 6500 | 20501 | 6292 | 7312 | 3.89 |
| 7000 | 22078 | 6776 | 7336 | 4.17 |
| 7500 | 23655 | 7260 | 7360 | 4.46 |

LATERAL PLACEMENT = 5 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1482 | 452 | 7022 | 0.29 |
| 1000 | 2964 | 904 | 7044 | 0.58 |
| 1500 | 4446 | 1356 | 7066 | 0.87 |
| 2000 | 5928 | 1808 | 7088 | 1.16 |
| 2500 | 7410 | 2260 | 7110 | 1.45 |
| 3000 | 8892 | 2712 | 7132 | 1.73 |
| 3500 | 10374 | 3164 | 7154 | 2.02 |
| 4000 | 11856 | 3616 | 7176 | 2.30 |
| 4500 | 13338 | 4068 | 7198 | 2.58 |
| 5000 | 14820 | 4520 | 7220 | 2.85 |
| 5500 | 16302 | 4972 | 7242 | 3.13 |
| 6000 | 17784 | 5424 | 7264 | 3.40 |
| 6500 | 19266 | 5876 | 7286 | 3.68 |
| 7000 | 20748 | 6328 | 7308 | 3.95 |
| 7500 | 22230 | 6780 | 7330 | 4.22 |

LATERAL PLACEMENT = 6 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1394 | 422 | 7021 | 0.28 |
| 1000 | 2788 | 844 | 7042 | 0.55 |
| 1500 | 4182 | 1266 | 7063 | 0.83 |
| 2000 | 5576 | 1688 | 7084 | 1.10 |
| 2500 | 6970 | 2110 | 7105 | 1.37 |
| 3000 | 8364 | 2532 | 7126 | 1.64 |
| 3500 | 9758 | 2954 | 7147 | 1.90 |
| 4000 | 11152 | 3376 | 7168 | 2.17 |
| 4500 | 12546 | 3798 | 7189 | 2.43 |
| 5000 | 13940 | 4220 | 7210 | 2.70 |
| 5500 | 15334 | 4642 | 7231 | 2.96 |
| 6000 | 16728 | 5064 | 7252 | 3.22 |
| 6500 | 18122 | 5486 | 7273 | 3.47 |
| 7000 | 19516 | 5908 | 7294 | 3.73 |
| 7500 | 20910 | 6330 | 7315 | 3.99 |

LATERAL PLACEMENT = 7 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1314 | 397 | 7020 | 0.26 |
| 1000 | 2628 | 794 | 7040 | 0.52 |
| 1500 | 3942 | 1191 | 7060 | 0.78 |
| 2000 | 5256 | 1588 | 7080 | 1.04 |
| 2500 | 6570 | 1985 | 7100 | 1.29 |
| 3000 | 7884 | 2382 | 7120 | 1.55 |
| 3500 | 9198 | 2779 | 7140 | 1.80 |
| 4000 | 10512 | 3176 | 7160 | 2.05 |
| 4500 | 11826 | 3573 | 7180 | 2.30 |
| 5000 | 13140 | 3970 | 7200 | 2.55 |
| 5500 | 14454 | 4367 | 7220 | 2.79 |
| 6000 | 15768 | 4764 | 7240 | 3.04 |
| 6500 | 17082 | 5161 | 7260 | 3.28 |
| 7000 | 18396 | 5558 | 7280 | 3.53 |
| 7500 | 19710 | 5955 | 7300 | 3.77 |

LATERAL PLACEMENT = 8 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1239 | 373 | 7018 | 0.25 |
| 1000 | 2478 | 746 | 7036 | 0.49 |
| 1500 | 3717 | 1119 | 7054 | 0.74 |
| 2000 | 4956 | 1492 | 7072 | 0.98 |
| 2500 | 6195 | 1865 | 7090 | 1.22 |
| 3000 | 7434 | 2238 | 7108 | 1.46 |
| 3500 | 8673 | 2611 | 7126 | 1.70 |
| 4000 | 9912 | 2984 | 7144 | 1.94 |
| 4500 | 11151 | 3357 | 7162 | 2.18 |
| 5000 | 12390 | 3730 | 7180 | 2.41 |
| 5500 | 13629 | 4103 | 7198 | 2.65 |
| 6000 | 14868 | 4476 | 7216 | 2.88 |
| 6500 | 16107 | 4849 | 7234 | 3.11 |
| 7000 | 17346 | 5222 | 7252 | 3.34 |
| 7500 | 18585 | 5595 | 7270 | 3.57 |

LATERAL PLACEMENT = 9 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1170 | 352 | 7017 | 0.23 |
| 1000 | 2340 | 704 | 7034 | 0.47 |
| 1500 | 3510 | 1056 | 7051 | 0.70 |
| 2000 | 4680 | 1408 | 7068 | 0.93 |
| 2500 | 5850 | 1760 | 7085 | 1.15 |
| 3000 | 7020 | 2112 | 7102 | 1.38 |
| 3500 | 8190 | 2464 | 7119 | 1.61 |
| 4000 | 9360 | 2816 | 7136 | 1.83 |
| 4500 | 10530 | 3168 | 7153 | 2.06 |
| 5000 | 11700 | 3520 | 7170 | 2.28 |
| 5500 | 12870 | 3872 | 7187 | 2.50 |
| 6000 | 14040 | 4224 | 7204 | 2.73 |
| 6500 | 15210 | 4576 | 7221 | 2.95 |
| 7000 | 16380 | 4928 | 7238 | 3.16 |

LATERAL PLACEMENT = 10 ft.

| ADT | ACC. COST | ACC. COST | INSTALLATION COST | B:C |
|---|---|---|---|---|
| 500 | 1104 | 332 | 7016 | 0.22 |
| 1000 | 2208 | 664 | 7032 | 0.44 |
| 1500 | 3312 | 996 | 7048 | 0.66 |
| 2000 | 4416 | 1328 | 7064 | 0.87 |
| 2500 | 5520 | 1660 | 7080 | 1.09 |
| 3000 | 6624 | 1992 | 7096 | 1.31 |
| 3500 | 7728 | 2324 | 7112 | 1.52 |
| 4000 | 8832 | 2656 | 7128 | 1.73 |
| 4500 | 9936 | 2988 | 7144 | 1.95 |
| 5000 | 11040 | 3320 | 7160 | 2.16 |
| 5500 | 12144 | 3652 | 7176 | 2.37 |
| 6000 | 13248 | 3984 | 7192 | 2.58 |
| 6500 | 14352 | 4316 | 7208 | 2.78 |
| 7000 | 15456 | 4648 | 7224 | 2.90 |

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