USERS MANUAL
(TRAFFIC) TSD/M/BARRIER/EVAL on TRAFFIC

COST-EFFECTIVENESS EVALUATION OF BARRIERS

TRAFFIC and SAFETY DIVISION

MICHIGAN DEPARTMENT OF TRANSPORTATION

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Appendix A: Excerpt from A Supplement to "A Guide for Selecting, Designing, and Locating Traffic Barriers" (1980).

USERS MANUAL
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COST-EFFECTIVENESS EVALUATION OF BARRIERS

INTRODUCTION

Computer program TSD/M/BARRIER/EVAL calculates the estimated annual costs for different alternatives for barriers and obstacles. To use this program, the evaluator first builds a small data file that describes the location and the barrier alternatives. This file is read in by the program, which then calculates the estimated annual cost for each alternative and prints a one-page report, tabulating those costs. In theory, the alternative with the lowest annual cost would be the most cost-effective.

The evaluation technique used is taken from A Supplement to "A Guide for Selecting, Designing, and Locating Traffic Barriers", by the Texas Transportation Institute (March 1980). The "Guide" was published by AASHTO in 1977. Pages 25 through 48 of the Supplement are included in Appendix A of this manual.

The values in the cost-comparison table must be used only in their proper context. The calculated values are highly sensitive to a number of assumed variables, such as accident costs, severity of impact, and frequency of collisions. The costs are intended to be used for relative comparison only -- values from one table should not be used with values from another table that is based on other assumed values.

The values in the table are, at best, accurate to within 20 percent of the true value. The user is cautioned to not credit the computer-written table with a higher degree of accuracy than is warranted.

The cost-effectiveness evaluation is only one of the criteria used to select barriers. The evaluator must select the barrier type that has the best attributes overall, even though it may not show to be the most cost-effective or have the fewest number of expected impacts.

OPERATING INSTRUCTIONS

To run program TSD/M/BARRIER/EVAL, the user must first build an input data file, then run the program and call in that data file.

The program can also print an "Audit Report." This optional report traces the program run, showing key variables as the program enters and exits subroutines. It is useful as a work sheet if the user needs to know some of the intermediate values, such as expected collision frequency or loss due to a collision.

STEP	ACTION

I. Build Input Data File

1. Log onto any terminal under any user code.

2. Enter MAKE <file title> DATA

   Follow the file naming conventions for your user code. For TRAFFIC, use your last name followed by any descriptors you like, to help you recognize the file.

3. Make the input data file. See "INPUT FILE," page 4, for details. When finished making or editing the file, be certain the current version is SAVEd before running the program.

II. Running the Program

4. Enter

   Run (TRAFFIC) TSD/M/BARRIER/EVAL on TRAFFIC; %
   PROCESSTIME = 10; VALUE = 1; %
   FILE FILE1 (TITLE = <file title>)

   The VALUE statement is optional; if used, the Audit Trail report is printed. If omitted or if VALUE equals something other than 1, the Audit Trail is not printed.

   The FILE title attribute is required; it informs the program which input file is to be used. Be certain that the file name is exactly correct; if the wrong name is used, the computer will either (a) give a NO FILE message, or (b) use a file you did not intend to use.

5. After the run is completed (in just a few seconds), log off and await your printout.

6. Check your output report. If the results do not look reasonable, check your input data file.

Some checking of the input data is performed when the file is read in. If an error is found, a DATA ERROR message will be printed and the run will be ended. If during a run the program needs data that is missing, a RUNNING ERROR message will be printed in the cost-comparison table. The program will run to completion but the values may be wrong. See "ERROR MESSAGES," page 8, for more information.

7. When finished with your data file, remove it from the disk.

INPUT FILE

Program TSD/M/BARRIER/EVAL requires a small data file (10 to 92 records) that describes (a) the location and (b) each of the various alternatives. Up to nine alternatives are allowed in the program; the first is always the "Do-nothing" alternative, and describes the existing condition. Each alternative can consist of up to four separate elements.

Each line of the data file begins with three one-digit codes that identify the alternative, element, and line number, in Columns 2, 3, and 4. The remainder of the data on each line, beginning on Column 6, is in one of six formats, depending on the values in the first three codes. Columns 1 and 5 are blank in every record.

The different formats are described below, with an example file listing shown in Figure 1. Items marked with "(R)" are transferred directly to the output report and are not otherwise used in the program.

The CANDE "PAGE" command can be used on an EECO or Lear-Siegler ADM terminal to determine which column the cursor is on, as that command displays a scale of column numbers at the top of the terminal's screen. Another convenient method for checking for accuracy of placement is the "LIST @ n-m" command, where n and m are column numbers. For example, to check the placement of severity codes, enter LIST @ 29-32:Z. Those four columns of all records will be displayed; those records with a severity index should show that data in the form 00.0.

To obtain a printed listing of the file a convenient type size (10 characters per inch) enter WRITE <file>; FILE LINE(PPJOBID = NO8, PPFORMAT = NO812).

```
MERCER/GRAIL/TESTDATA/2 (06/18/84) [DATA]

     100      001 5 34043        1  13000  20 10.0                   Don Mercer
     200      002 Large Culverts on I-96, Various Locations, Ionia County
     300      011 200000.  10000.    700.
     400      101 Culvert with headwall located about 40 ft
     500      102 from Edge of Pavement on 1:3 slope
     600      111 09-00-0-0 0025 20 40 0  6.5
     700      112 00000.00   00000.00   00000.00   00000.00
     800      121 07-01-0-0  175 30 10 0  3.5
     900      122     0.00       0.00       0.00       0.00
    1000      201 Install 150 ft Type B Guardrail and End Section
    1100      202  on 1:10 slope, at 22 ft offest
    1200      211 06-01-1-0  125  1 27 1  3.7
    1300      212 03025.00 0 00001.50 1 00001.50 1 00500.00
    1400      221 06-01-1-1   50  1 22 1 03.3
    1500      222    00.00 1     1.50 1     1.50 1   200.00
    1600      301 Install 150 ft Type B Guardrail and End Section
    1700      302  on 1:6 slope, at 22 ft offest
    1800      311 06-01-1-0  125  1 27 1  3.7
    1900      312 02775.00 0 00001.50 1 00001.50 1 00500.00
    2000      321 06-01-1-1   50  1 22 1 03.3
    2100      322    00.00 1     1.50 1     1.50 1   200.00
    2200      401 Install 200 ft Type B Guardrail and End Section
    2300      402 at 13 ft offset
    2400      411 06-01-1-0  175  1 13 1  3.7
    2500      412  2675.00       1.50 1     1.50 1   500.00
    2600      421 06-01-1-1   50  1 13 1  3.3
    2700      422     0.00       1.50 1     1.50 1   200.00
```

Figure 1
Example input file listing (FILE1)

ALTERNATIVE CODE = 0: LOCATION INFORMATION

The file contains two or three lines that describe the location and provide data that apply to all alternatives:

Element Code = 0, Line Number = 1

Columns	Example	Format	Contents
2-4	001	3I1	Alternative, Element, and Line Number Codes.
6	1	A1	(R) District Number
8-12	54321	A5	(R) Control Section Number
14-18	43.21	A5	(R) Milepoint
20	1	I1	Type of Roadway This value is used to select the equation for rate of encroachment: 0: General, Uses equation on page 26 of supplement (about 0.0004111*ADT) 1: Rural Interstate (0.0009*ADT) 2: Rural Multi-lane or Divided (0.00059*ADT) 3: Wide Rural 2-Lane (0.000742*ADT) 4: Narrow Rural 2-Lane (0.00121*ADT) 5: Urban Interstate, Multi-lane, or Divided (0.0009*ADT) 6: Major Urban Arterial (0.00133*ADT) 7, 8, or 9: Treated as Code 0.
22-27	654321	I6	Two-way average Daily Traffic
29-31	321	I3	Life of the Alternatives, in whole number of years.
33-36	32.1	F4.1	Interest rate, in percent (for 8½%, enter 8.5, not 0.085)
38-55	(18ch)	3A6	(R) Space reserved for any other reference system the evaluator selects, such as structure number, guardrail run number, or railroad crossing number.
57-68	(12ch)	2A6	(R) Evaluator's Name.

Element Code = 0, Line Number = 2

Columns	Example	Format	Contents
2-4	002	3I1	Alternative, Element, and Line Number Codes
6-75	(70ch)	11A6,A4	(R) Written description of the location, such as route number, distance from landmark, direction.

Element Code = 1, Line Number = 1

This record is optional, and needed only to use accident cost data that is different from the default values.

Columns	Example	Format	Contents
2-4	011	3I1	Alternative, Element, and Line Number Codes
6-12	654321.	F7.0	Loss for a Fatal Accident (Default = \$300,000)
14-20	654321.	F7.0	Loss for an Injury Accident (Default = \$7,500)
22-28	654321.	F7.0	Loss for a Property-Damage Accident (Default = \$500).

ALTERNATIVE CODE = 1 THROUGH 9: ALTERNATIVES INFORMATION

Up to nine different alternative treatments can be evaluated by the program, of which Number 1 is always treated as the existing condition. Alternative numbers may be skipped; that is, for example, you could use Alternatives 1, 2, and 4.

Element Code = 0, Line Number = 1 or 2

The alternative is described in english, on two lines of 48 characters each. For Alternative 1, the description is printed as "Existing Condition", for other alternatives the description is printed in the cost-comparison table. The description should be complete, as it is the only information about the alternative that is printed in the main report. If the complete description will fit on one 48-character line, the second line may be omitted.

Column	Example	Format	Contents
2-4	i01	3I1	Alternative, Element, and Line Number Codes
6-53	(48ch)	8A6	(R) English description of Alternative

Element Code = 1 through 4: Element Information

Each alternative may consist of 1 to 4 elements. Element numbers may be skipped, except for elements that are connected together and act as a unit, such as a flared end section guardrail structural anchorage combination. Such combinations must be entered in consecutive element number, beginning with the upstream element.

Line Number = 1: Element Description

Column	Example	Format	Contents
2-4	ij1	3I1	Alternative, Element, and Line Number Codes The next 4 codes are given on pages 32 and 33 of the supplement. They are used to determine the severity index of the element, if that index is not given in Columns 29 to 32 of this record.
6-7	01	I2	Identification Code
9-10	01	I2	Descriptor Code
12	1	I1	Beginning End Treatment code
14	1	I1	Ending End Treatment Code

16-19	4321	I4	Horizontal length of the element in feet. If zero or negative, the element is skipped during the cost calculations.
21-22	21	I2	Width of the element, in feet.
24-25	21	I2	Lateral offset of the element, in feet, measured from the edge of pavement.
27	1	I1	Connected Flag. Enter 1 if the element is connected to the next downstream element, to act as a unit. Otherwise enter 0 or leave blank.
29-32	10.0	F4.1	Severity Index of the element, to a mazimum value of 10.0. If set at zero or not entered, severity index is determined, based on Table 5.1.12 of the Supplement (pages 34 and 35).

Line Number = 2: Cost Information

Four cost items are entered for the element; installation cost, annual maintenance cost, salvage value at the end of life, and cost to repair the element after an accident. Each cost item is followed by a unit price flag; enter 1 if the cost represents cost per foot or 0 (or leave blank) if the cost represents a lump sum.

Column	Example	Format	Contents
2-4	ij2	3I2	Alternative, Element, and Line Number Codes
6-13	54321.12	F8.2	Cost to install the element.
15	1	I2	Unit price flag for installation cost.
17-24	54321.12	F8.2	Annual maintenance costs for element.
26	1	I1	Unit price flag for maintenance cost.
28-35	54321.12	F8.2	Salvage value at the end of life span given in the "001" record. This value can be negative, when the cost to remove the element is more than its scrap value. All other costs must be positive.
37	1	I1	Unit price flag for salvage value.
39-46	54321.12	F8.2	Cost to repair the element after an accident.
48	1	I1	Unit price flag for repair cost.

ERROR MESSAGES

The program runs a number of checks of the data to trap some of the potential errors.

If an error is found when the input file is read in, the record and an error message is printed on the main report. The entire input file is read in and checked, but the program will then stop before calculating the costs.

If an error is found while the program is running, a message will be printed in the cost comparison table, and the run continues. The output values, especially for the alternative with the error, should not be used or trusted.

The user must check the file carefully, as the program will not perform all the possible checks. It cannot, for example, know that an installation cost of $25.00 should have been $2,500.00. The input data are not shown in the main report so errors of this nature may not be detected unless the calculated annual cost is grossly inaccurate. The optional audit trail shows some of the input data.

The error message, with some suggestions for correcting the data are:

DATA ERROR: Errors Detected When Reading Input

"Cannot read input record"
This message usually means that there is an alphabetic character where a numerical is expected, or that there is a decimal point where an integer number (I format) is expected. The data may be in the wrong columns. Also, check the first three codes (Columns 2 to 4). A mistake in those codes will cause the program to use the wrong format when reading the rest of the record.

"Maximum number of elements of an alternative is 4"
Check Column 3. The value is 5 or greater, so the program has no place to store the data.

"Line number must be either 0 or 1"
Check Column 4. The value is not one of those two values, so the program cannot determine which format to use.

"ADT cannot be negative"
Check Columns 22 through 27. The value for average daily traffic must be a positive integer or 0. If the value of 0 is used, the cost-comparison table will reflect only installation and maintenance costs and salvage value; accident and repair costs will not be included.

"Value of LIFE must be at least 1 year"
Check Columns 29 through 31. The value must be a positive integer greater than 0.

"INTEREST RATE cannot be negative"
Check Columns 32 through 36. The value must be a positive number or 0.0. If the value of 0.0 is used, the costs and salvage values are prorated uniformly over the LIFE span.

"WIDTH and OFFSET must be at least 1"
Check Columns 21 and 22 for WIDTH and 24 and 25 for OFFSET. Both must be positive integers greater than 0. If the LENGTH (Columns 16 through 19) is zero or negative, the element will not be included in the cost calculations. This enables the user to eliminate an alternative simply by putting a negative sign in Column 16 for the lengths of all elements in the alternative so it is not necessary to remove the data from the file.

"CONNECTED flag must be 0 or 1"
Check Column 27. The value should be 1 if the element is connected to the next downstream element (which should also be the next element in the file). Otherwise the value should be 0. A blank is accepted as a zero.

"Maximum value of SEVERITY INDEX is 10.0"
"SEVERITY INDEX cannot be negative"
Check Columns 29 through 32. The value must be a positive number between 0.0 and 10.0. If 0.0 (or blank), the program will use the element description codes to determine the SEVERITY INDEX of the element.

"Costs (except Salvage) cannot be negative"
Check Columns 6 through 13 (installation cost), 17 through 24 (annual maintenance cost), and 39 through 46 (damage repair cost). These must all be a positive number of 0.00 or more. Since SALVAGE value represents a return of money, a positive value is subtracted in the cost calculations and a negative value is added.

"UNIT PRICE flag must be 0 or 1"
Check Columns 15 (for installation cost), 26 (for annual maintenance cost), 37 (for salvage value), and 48 (for damage repair cost). The value should be 1 if the cost represents a cost per foot of the element. If the cost is a lump sum, the value should be 0 or blank.

"Accident Costs cannot be negative"
Check Columns 6 through 12 (Fatal Accident Costs), 14 through 20 (Personal Injury Accident Costs), and 22 through 28 (Property Damage Only Accident Costs). The values must all be positive integers or 0. If the value of 0 is used, the cost-comparison table will not reflect any loss to vehicles or occupants. The table will, however, include the cost to repair the damage barrier.

RUN TIME ERROR: Errors discovered during a run of the program

"Cannot determine severity Index for Alternative i.j"
Check the Element Description Codes (Columns 6 through 14) of the ijl record. When the severity (Columns 29 through 32) index is zero, the program obtains an index based on the Identification, Descriptor, and Beginning and Ending Treatment Codes. In this case, the codes used do not match any in the Severity Index Table (pages 34 and 35 of the Supplement).

"No Element Given to Connect to Alternative i.j"
Check the connected Flag (Column 27) of the ijl record. The value of 1 tells the program that this element is connected to alternative i.(j+1), but there is no such element in the file.

(TRAFFIC) TSD/M/BARRIER/EVAL on TRAFFIC

EXAMPLE RUN

Michigan Department of Transportation
Traffic and Safety Division
Safety Programs Unit

BARRIER SELECTION USING COST-EFFECTIVENESS

District 5 Control Section 34043 Milepoint

Location : Large Culverts on I-96, Various Locations, Ionia County

Existing Condition: Culvert with headwall located about 40 ft from Edge of Pavement on 1:3 slope

Cost Comparison

Alternative	Estimated Annual Cost 20-year Life @ 10.0%
1. "Do-Nothing" : Leave Existing Condition As Is	$ 2,062.
2. Install 150 ft Type B Guardrail and End Section on 1:10 slope, at 22 ft offest	$ 1,595.
3. Install 150 ft Type B Guardrail and End Section on 1:6 slope, at 22 ft offest	$ 1,566.
4. Install 200 ft Type B Guardrail and End Section at 13 ft offset	$ 2,954.

Use table values for relative comparisions only. Differences of 20 percent or less might not be meaningful.

by : Don Mercer
Nov 19, 1984

Michigan Department of Transportation
Traffic and Safety Division
Safety Programs Unit

BARRIER SELECTION USING COST-EFFECTIVENESS

A U D I T   T R A I L

File : (TRAFFIC)MERCER/GRAIL/TESTDATA/2 ON TRAFFIC.

Run 11/19/1984 @ 8:28

```
          10        20        30        40        50        60        70   75
 |....+....|....+....|....+....|....+....|....+....|....+....|....+....|....+|
 | 001 5 34043       1  13000  20 10.0                         Don Mercer   |
 | 002 Large Culverts on I-96, Various Locations, Ionia County               |
 | 011 200000.  10000.    700.                                               |
 | 101 Culvert with headwall located about 40 ft                             |
 | 102 from Edge of Pavement on 1:3 slope                                    |
 | 111 09-00-0-0 0025 20 40 0  6.5                                           |
 | 112 00000.00   00000.00   00000.00   00000.00                             |
 | 121 07-01-0-0  175 30 10 0  3.5                                           |
 | 122      0.00        0.00        0.00        0.00                         |
 | 201 Install 150 ft Type B Guardrail and End Section                       |
 | 202  on 1:10 slope, at 22 ft offest                                       |
 | 211 06-01-1-0  125  1 27 1  3.7                                           |
 | 212 03025.00 0 00001.50 1 00001.50 1 00500.00                             |
 | 221 06-01-1-1   50  1 22 1 03.3                                           |
 | 222     00.00 1      1.50 1      1.50 1   200.00                          |
 | 301 Install 150 ft Type B Guardrail and End Section                       |
 | 302  on 1:6 slope, at 22 ft offest                                        |
 | 311 06-01-1-0  125  1 27 1  3.7                                           |
 | 312 02775.00 0 00001.50 1 00001.50 1 00500.00                             |
 | 321 06-01-1-1   50  1 22 1 03.3                                           |
 | 322     00.00 1      1.50 1      1.50 1   200.00                          |
 | 401 Install 200 ft Type B Guardrail and End Section                       |
 | 402 at 13 ft offset                                                       |
 | 411 06-01-1-0  175  1 13 1  3.7                                           |
 | 412  2675.00         1.50 1      1.50 1   500.00                          |
 | 421 06-01-1-1   50  1 13 1  3.3                                           |
 | 422      0.00        1.50 1      1.50 1   200.00                          |
 |....+....|....+....|....+....|....+....|....+....|....+....|....+....|....+|
```

```
ACCIDENT COSTS USED    Fatal : 200,000.
                      Injury :  10,000.
                   Prop Damg :     700.
```

```
INTERMEDIATE CALCULATIONS FOR 1.  (2 Elements in Alternative)

ENTERING CFREQ for (1,1)   [Road Type 1      ADT =  13,000]
   Horizontal Length =   25.0
               Width =   20.0
      Lateral Offset =   40.0
    Effective Length =   25.0

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.0059

ENTERING CFREQ for (1,2)   [Road Type 1      ADT =  13,000]
   Horizontal Length =  175.0
               Width =   30.0
      Lateral Offset =   10.0
    Effective Length =  175.0

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.2718

ENTERING ECONAL   [Life =  20 Years   Interest Rate =  10.0%]
```

```
  Cost (1,1,1,1) =     0.00
  Cost (1,1,2,1) =     0.00
  Cost (1,1,3,1) =     0.00
  Cost (1,1,4,1) =     0.00
    Occupant/Veh Loss per Accident =  48,505.00 (Severity Index =  6.5)

  Cost (1,1,1,1) =     0.00
  Cost (1,1,2,1) =     0.00
  Cost (1,1,3,1) =     0.00
  Cost (1,1,4,1) =     0.00
  Cost (1,1,5,1) =   286.75

  Cost (1,2,1,1) =     0.00
  Cost (1,2,2,1) =     0.00
  Cost (1,2,3,1) =     0.00
  Cost (1,2,4,1) =     0.00
    Occupant/Veh Loss per Accident =   6,532.50 (Severity Index =  3.5)

  Cost (1,2,1,1) =     0.00
  Cost (1,2,2,1) =     0.00
  Cost (1,2,3,1) =     0.00
  Cost (1,2,4,1) =     0.00
  Cost (1,2,5,1) =  1775.33

 EXITING ECONAL
  Cost (1,4,5,2) =  2062.08


 INTERMEDIATE CALCULATIONS FOR 2.  (2 Elements in Alternative)

ENTERING CFREQ for (2,1)    [Road Type 1     ADT =  13,000]
   Horizontal Length =  125.0
               Width =    1.0
      Lateral Offset =   27.0
    Effective Length =  125.0

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.0832

ENTERING CFREQ for (2,2)    [Road Type 1     ADT =  13,000]
   Horizontal Length =   50.0
               Width =    1.0
      Lateral Offset =   22.0
    Effective Length =   18.6

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.0563

ENTERING ECONAL    [Life =  20 Years    Interest Rate = 10.0%]

  Cost (2,1,1,1) =  3025.00
  Cost (2,1,2,1) =   187.50
  Cost (2,1,3,1) =   187.50
  Cost (2,1,4,1) =   500.00
    Occupant/Veh Loss per Accident =   7,191.50 (Severity Index =  3.7)

  Cost (2,1,1,1) =   355.32
  Cost (2,1,2,1) =   187.50
  Cost (2,1,3,1) =    -3.27
  Cost (2,1,4,1) =    41.59
  Cost (2,1,5,1) =   598.22

  Cost (2,2,1,1) =     0.00
  Cost (2,2,2,1) =    75.00
  Cost (2,2,3,1) =    75.00
  Cost (2,2,4,1) =   200.00
    Occupant/Veh Loss per Accident =   5,873.50 (Severity Index =  3.3)

  Cost (2,2,1,1) =     0.00
  Cost (2,2,2,1) =    75.00
  Cost (2,2,3,1) =    -1.31
  Cost (2,2,4,1) =    11.26
  Cost (2,2,5,1) =   330.81

 EXITING ECONAL
  Cost (2,4,5,2) =  1595.12
```

```
 INTERMEDIATE CALCULATIONS FOR 3.  (2 Elements in Alternative)

ENTERING CFREQ for (3,1)   [Road Type 1      ADT =  13,000]
   Horizontal Length =  125.0
               Width =    1.0
      Lateral Offset =   27.0
    Effective Length =  125.0

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.0832

ENTERING CFREQ for (3,2)   [Road Type 1      ADT =  13,000]
   Horizontal Length =   50.0
               Width =    1.0
      Lateral Offset =   22.0
    Effective Length =   18.6

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.0563

ENTERING ECONAL    [Life =  20 Years   Interest Rate = 10.0%]

  Cost (3,1,1,1) =  2775.00
  Cost (3,1,2,1) =   187.50
  Cost (3,1,3,1) =   187.50
  Cost (3,1,4,1) =   500.00
    Occupant/Veh Loss per Accident =   7,191.50 (Severity Index =  3.7)

  Cost (3,1,1,1) =   325.95
  Cost (3,1,2,1) =   187.50
  Cost (3,1,3,1) =    -3.27
  Cost (3,1,4,1) =    41.59
  Cost (3,1,5,1) =   598.22

  Cost (3,2,1,1) =     0.00
  Cost (3,2,2,1) =    75.00
  Cost (3,2,3,1) =    75.00
  Cost (3,2,4,1) =   200.00
    Occupant/Veh Loss per Accident =   5,873.50 (Severity Index =  3.3)

  Cost (3,2,1,1) =     0.00
  Cost (3,2,2,1) =    75.00
  Cost (3,2,3,1) =    -1.31
  Cost (3,2,4,1) =    11.26
  Cost (3,2,5,1) =   330.81

 EXITING ECONAL
  Cost (3,4,5,2) =  1565.75


 INTERMEDIATE CALCULATIONS FOR 4.  (2 Elements in Alternative)

ENTERING CFREQ for (4,1)   [Road Type 1      ADT =  13,000]
   Horizontal Length =  175.0
               Width =    1.0
      Lateral Offset =   13.0
    Effective Length =  175.0

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.2346

ENTERING CFREQ for (4,2)   [Road Type 1      ADT =  13,000]
   Horizontal Length =   50.0
               Width =    1.0
      Lateral Offset =   13.0
    Effective Length =   18.6

 EXITING CFREQ
    Encroachment Rate =  11.7000
   Collision Frquency =   0.0829

ENTERING ECONAL    [Life =  20 Years   Interest Rate = 10.0%]

  Cost (4,1,1,1) =  2675.00
  Cost (4,1,2,1) =   262.50
```

```
 Cost (4,1,3,1) =   262.50
 Cost (4,1,4,1) =   500.00
   Occupant/Veh Loss per Accident =   7,191.50 (Severity Index =  3.7)

 Cost (4,1,1,1) =   314.20
 Cost (4,1,2,1) =   262.50
 Cost (4,1,3,1) =    -4.58
 Cost (4,1,4,1) =   117.28
 Cost (4,1,5,1) =  1686.87

 Cost (4,2,1,1) =     0.00
 Cost (4,2,2,1) =    75.00
 Cost (4,2,3,1) =    75.00
 Cost (4,2,4,1) =   200.00
   Occupant/Veh Loss per Accident =   5,873.50 (Severity Index =  3.3)

 Cost (4,2,1,1) =     0.00
 Cost (4,2,2,1) =    75.00
 Cost (4,2,3,1) =    -1.31
 Cost (4,2,4,1) =    16.59
 Cost (4,2,5,1) =   487.15

EXITING ECONAL
 Cost (4,4,5,2) =  2953.70

END OF RUN
```

APPENDIX A

Excerpt from

A Supplement to "A Guide for Selecting, Designing, and Locating Traffic Barriers" (1980)

REVISED
A COST-EFFECTIVENESS SELECTION
PROCEDURE FOR BARRIERS

Introduction - This section contains a revised cost-effectiveness procedure for selection of barriers. The primary difference is the change for present worth analysis to annual cost analysis, thus, permitting comparison of alternatives of different service lives.

Introduction

Collisions involving vehicles with roadside objects represent a problem inherent to any existing highway facility. Consequently, roadside safety improvement programs have evolved to provide guidance in eliminating those problem locations where attention is vitally needed. For the most part, these programs share the following policy base.

- Obstacles which may be removed should be eliminated.

- Obstacles which may not be removed should be relocated laterally or in a more protected position.

- Obstacles which may not be moved should be reduced in impact severity. Breakaway devices and flattened side slopes offer such an improvement.

- Obstacles which may not be otherwise treated should be shielded by attenuation or deflection devices.

While the above mentioned points of design summarize the available alternatives, the questions of "where, when or how" are often left unanswered. Limited funds are also a factor most agencies face. The designer is thus confronted with the problem of selecting those alternatives which offer the greatest return in terms of safety benefits.

The purpose of this cost-effective selection procedure is to provide a technique for comparing alternate solutions to problem locations. Present value of the total cost of each alternative is computed over a given period of time, taking into consideration initial costs, maintenance costs, and accident costs. Accident costs incurred by the motorist, including vehicle damage and personal injury, are considered together with accident costs incurred by the highway department or agency. Selection of the alternative with the least total cost would normally be made.

With regard to traffic barriers, the cost-effective procedure can be used to evaluate three alternatives:

1. Remove or reduce hazard so that shielding is unnecessary;

2. Install a barrier; or

3. Do nothing, i.e., leave hazard unshielded.

The third option normally would be cost effective only on low volume and/or low speed facilities, or where the probability of accidents is low. With regard to item 2, the procedure allows one to evaluate any number of barriers that can be used to shield the hazard. Each location and its alternatives should be approached on an individual basis. Through this method the effects of average daily traffic, offset of barrier or hazard, size of barrier or hazard, and the relative severity of the barrier or the hazard can be evaluated.

The procedure presented herein has been adopted from the work of Ross, et.al. (1) and permits objective evaluation of the options at a given site. The procedure included in this document is more generally applicable and is recommended for general use.

5.1.62 Applications

Implementation of the cost-effective procedure primarily involves the determination of several input values. The computations are simple and require only basic mathematics. It should be noted that during the course of the text, the work "obstacle" is used quite frequently. In this context, the term is meant to apply to either a hazard or improvement, whichever the case may be. The following steps summarize the procedure to be followed in the cost-effective analysis.

1. From existing or proposed geometry determine the following:

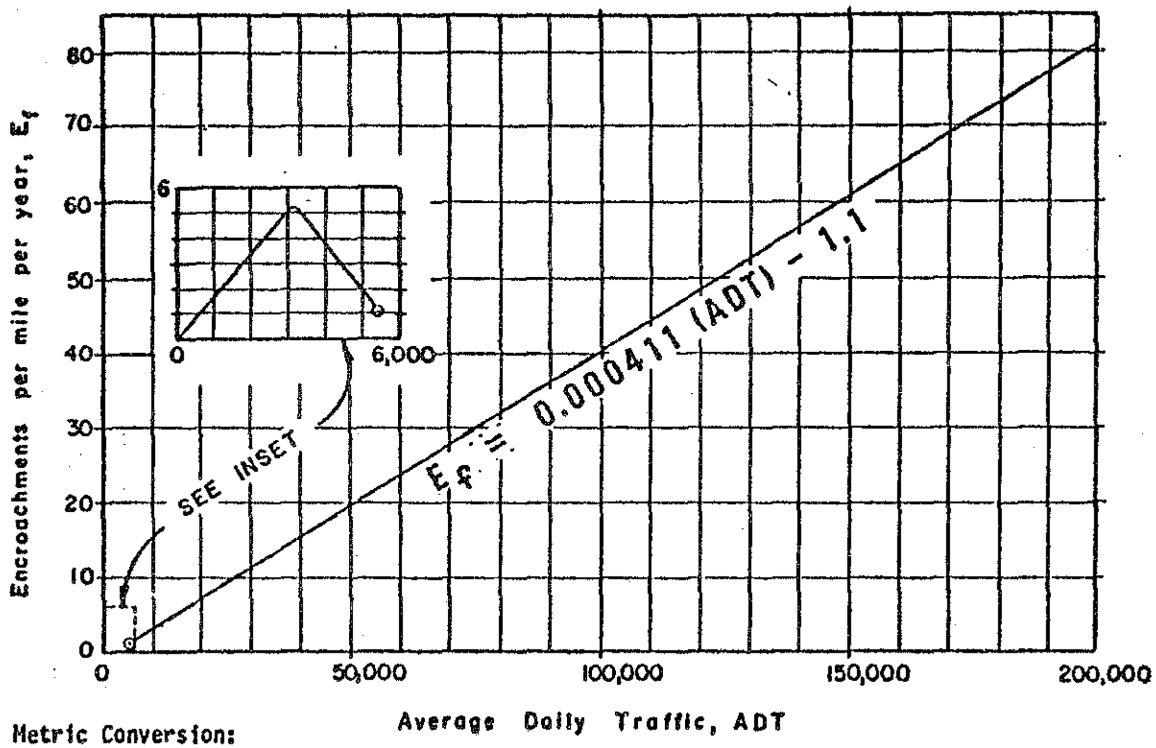
   A = lateral placement of the roadside obstacle from EOP (in feet).

   L = horizontal length of the roadside obstacle (in feet).

   W = width of the roadside obstacle (in feet).

2. From volume counts or estimates, determine the average daily traffic, ADT (vehicles per day). This value should represent the two-way volume flow.

3. Determine the encroachment frequency, E (vehicle encroachments per mile per year), from Figure 5.1.16. Figure 5.1.16 was obtained from data discussed previously. Other available data or



Metric Conversion:

1 Encroachment/mi =

.6214 Encroachments/km

Figure 5.1.16 Encroachment Frequency

adjustments of the above may be used at the discretion of the designer. This latitude offers an option to the user and helps to preserve the generality of the model.

4. Determine the collision frequency, C_f (accidents per year), from the appropriate nomograph given in Figures 5.1.17 and 5.1.18 (dependent on obstacle length). The nomographs combine the over-all geometry with a given encroachment frequency to yield the collision frequency. Collision frequency, C_f, is the predicted number of times a given obstacle will be impacted by an errant vehicle per year. The nomographs are used in the following manner.

- Locate and mark the encroachment frequency, E_f, on vertical axis (1)
- On horizontal axis (2) locate the lateral placement, A, and construct a vertical reference line the full height of the graph.
- Locate and mark the point where the lateral placement reference line intersects the width, W, curve in consideration.
- Project a horizontal line to the right from that point to the vertical axis (3) and mark the point of intersection.
- Locate and mark the point where the lateral placement reference line intersects the length, L, curve in consideration.
- Project a horizontal line to the left from this point to the vertical axis (4) and mark the point of intersection.
- Lay a straight-edge across the points marked on (3) and (4) and construct a line to intersect vertical axis (5). Mark the point of intersection.
- From the point determined construct a line to vertical axis (6) keeping approximately parallel to guidelines. Mark the point of intersection.
- Lay a straight-edge across the marked points on vertical axes (1) and (6) and construct a line connecting the two. Read the collision frequency, C_f, where the line intersects the collision frequency axis.

An example demonstrating the application of one of the nomographs is given in Figure 5.1.19. It may be necessary to adjust the collision frequency in locations where the geometry and traffic conditions are critical. Off-ramp gore areas represent such a situation, and an upward adjustment factor of 3 has been suggested. Mathematically, the collision frequency is given in the expression below.

$$C_f = \frac{E_f}{10,560}\left[(L + 62.9) \cdot P[Y \geq A] + 5.14 \sum_{J=1}^{J=W} P\left[Y \geq A + 6.0 + \frac{2J - 1}{2}\right]\right]$$

where,

the variables A, L, W and E are as previously defined

and,

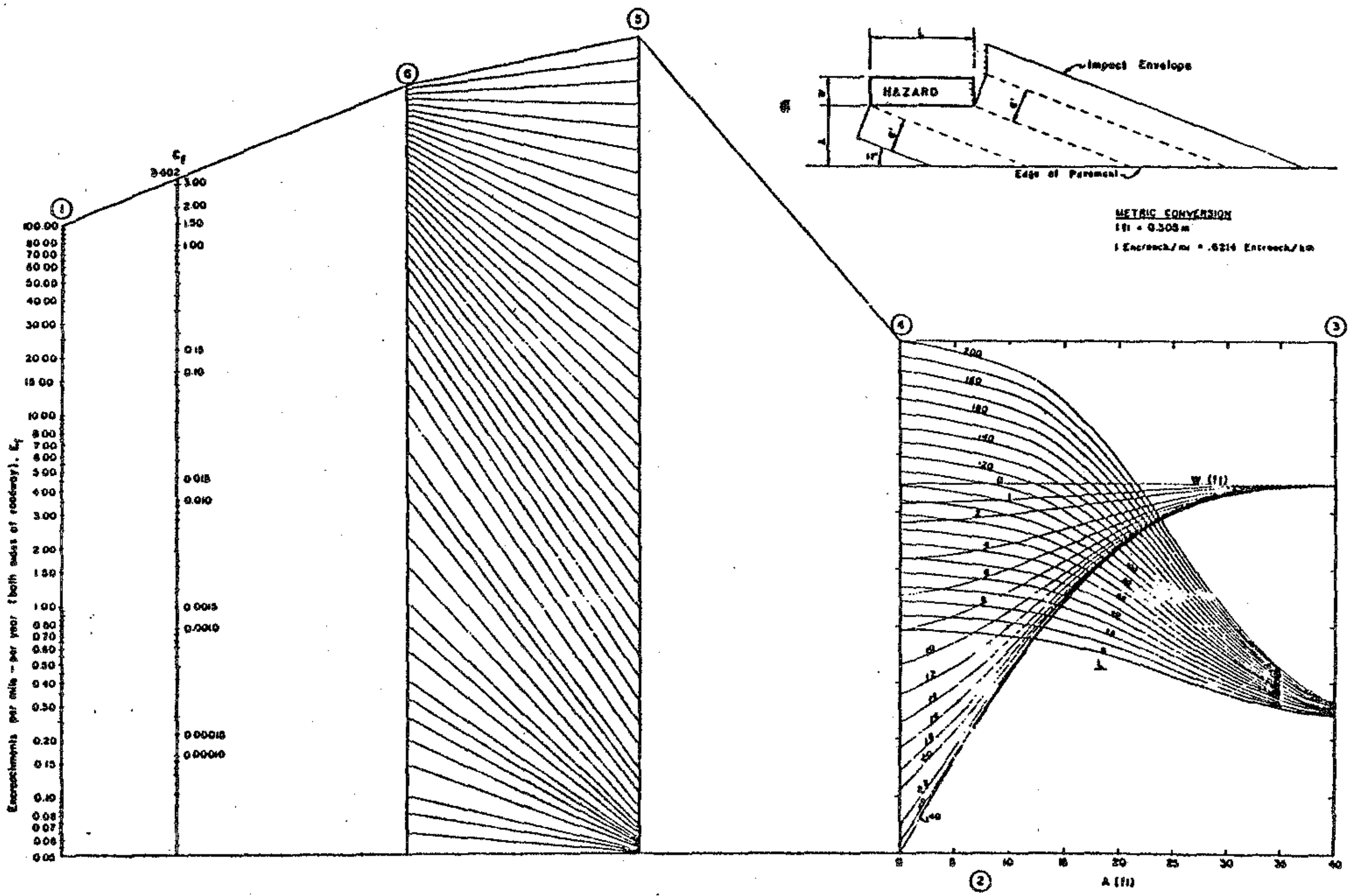
Y = the lateral displacement, in feet (metres), of the encroaching vehicle, measured from the edge of the traveled way to the longitudinal face of the roadside obstacle;

$P[Y > \ldots]$ = probability of a vehicle lateral displacement greater than some value. These probabilities may be taken from Figure 5.1.20;

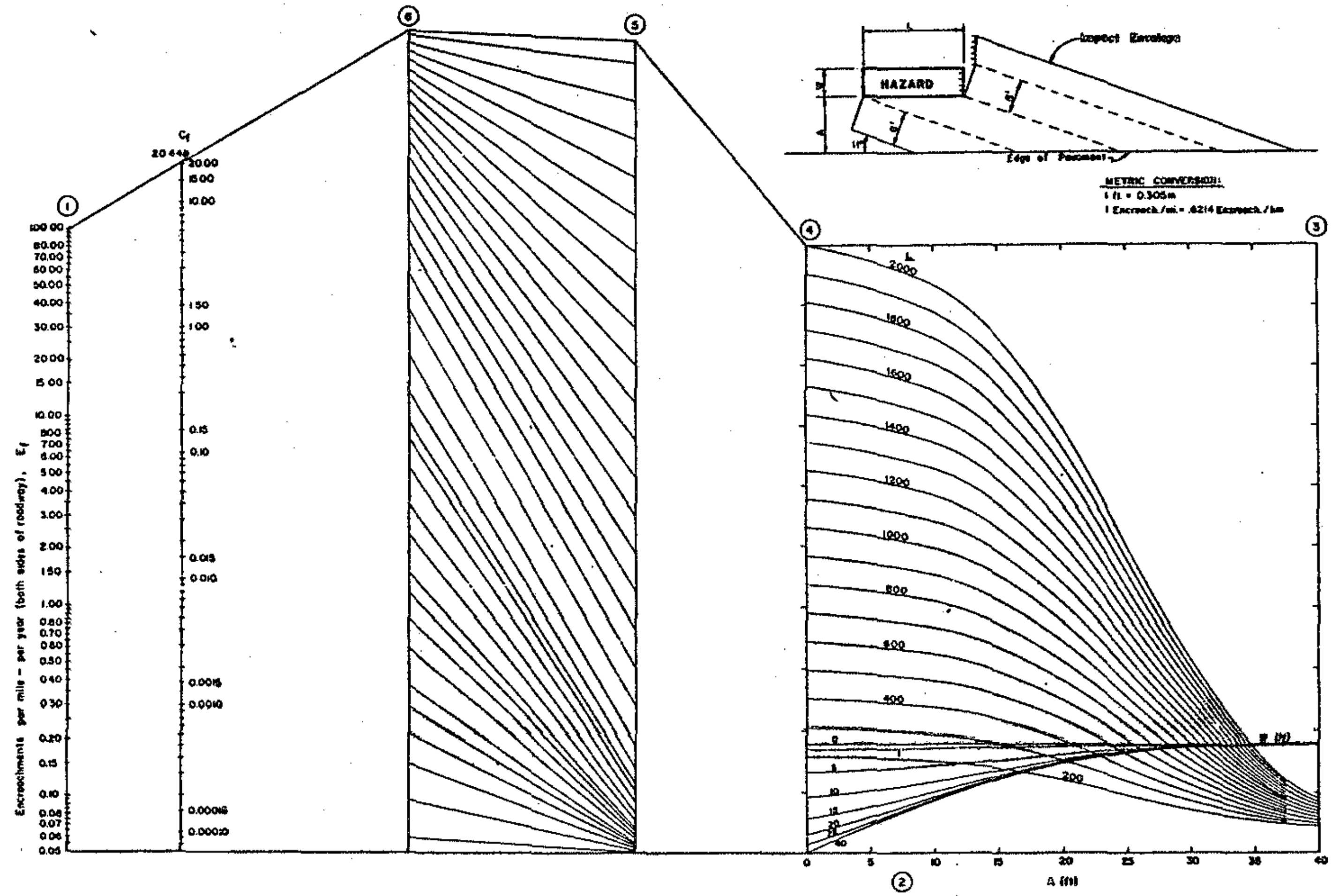
and

J = the number of the 1-ft (.3 m) wide obstacle-width increment under investigation. (If the obstacle is not a whole number of feet (metres) wide, the number of increments investigated is obtained by rounding the width down to the nearest whole foot (metre).

5. Assign a severity index to the obstacle of concern. Hazards can be denoted according to the hazard classification codes given in Table 5.1.11. It is suggested that the severity index be chosen on a scale of 0 to 10 according to the criteria given in Table 5.1.12. For example, if it is estimated that an impact with the obstacle will result in injuries or a fatality 60 percent of the time, select an index of 7. Corresponding to the index is an estimated accident cost which includes those costs associated with vehicle damage and occupant injuries and/or fatalities. Figure 5.1.21 is a graphic representation of accident cost versus severity index. Discretion is advised in assigning severity indices and the designer is encouraged to exhaust all available objective data before resorting to judgment.



Collision Frequency Nomograph Lengths from 0 - 200 Feet



Collision Frequency Nomograph Lengths from 200 - 2000 Feet

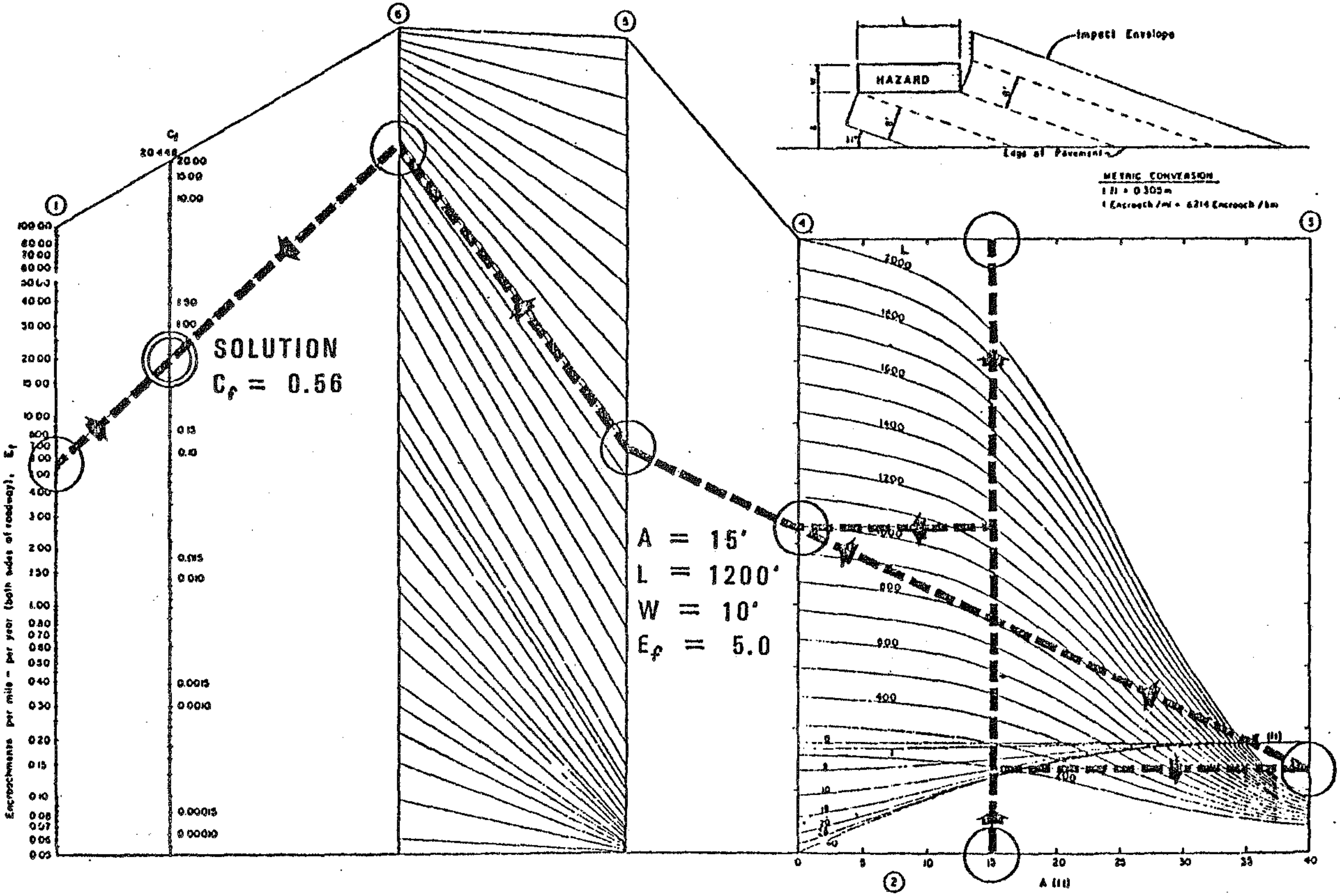
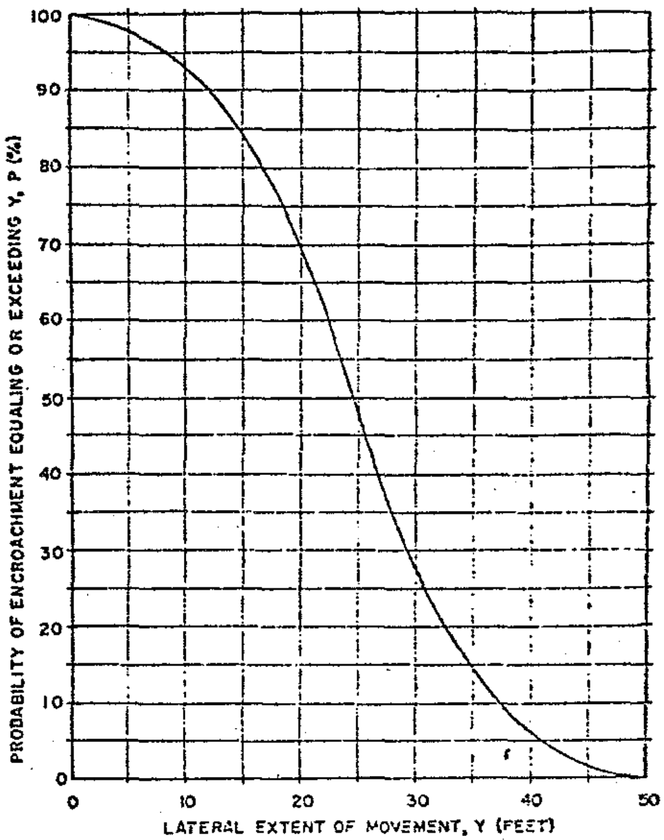


Figure 5.1-19 Collision Frequency Nomograph, Length From 200-2000 Feet (Example Solution)



1 ft. = .305 m

Figure 5.1.20 Lateral Displacement Distribution

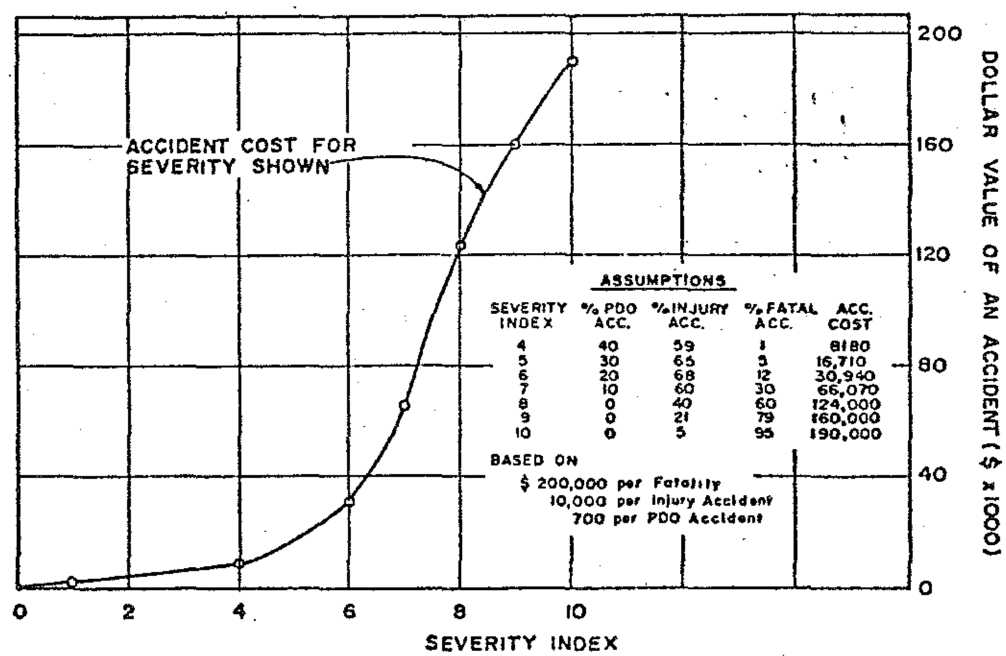


Figure 5.1.21 Average Occupant Injury and Vehicle Damage Costs (2)

TABLE 5.1.11 HAZARD CLASSIFICATION CODES

Note: Circled Codes denote Point Hazard

Identification Code		Descriptor Codes
(01.)	Utility Poles	(00)
(02.)	Trees	(00)
(03.)	Rigid Signpost	(01) single-pole-mounted (02) double-pole-mounted (03) triple-pole-mounted (04) cantilever support (05) overhead sign bridge
(04.)	Rigid Base Luminaire Support	(00)
05.	Curbs	(01) mountable design (02) non-mountable design less than 10 inches high (03) barrier design greater than 10 inches high
06.	Guardrail or Median Barrier	(01) w-section with standard post spacing (6 ft-3 in.) (including departing guardrail at bridge) (02) w-section with other than standard post spacing (including departing guardrail at bridge) (03) approach guardrail to bridge--decreased post spacing (3 ft-1 in.) adjacent to bridge (04) approach guardrail to bridge--post spacing not decreased adjacent to bridge (05) post and cable (06) Metal Beam Guard Fence (Barrier) (in median) (07) median barrier (CMB design or equivalent
07.	Roadside Slope	(01) sod positive slope (02) sod negative slope (03) concrete-faced positive slope (04) concrete-faced negative slope (05) rubble rip-rap positive slope (06) rubble rip-rap negative slope

GUARDRAIL END TREATMENT CODES

1 Not beginning or ending at structure-Safety treated
2 Not beginning or ending at structure-Not safety treated
3 Beginning or ending at structure-Full-beam connection
4 Beginning or ending at structure-Not full-beam connection

TABLE 5.1.11 (cont.)

08.	Ditch (includes erosion, rip-rap runoff ditches, etc.—does not include ditches formed by intersection of front and back slopes	(00)	
09.	Culverts	(01)	headwall (or exposed end of pipe culvert)
		(02)	gap between culverts on parallel roadways
		(03)	sloped culvert with grate
		(04)	sloped culvert without grate
10.	Inlets	(01)	raised drop inlet (tabletop)
		(02)	depressed drop inlet
		(03)	sloped inlet
11.	Roadway under Bridge Structure	(01)	bridge piers
		(02)	bridge abutment, vertical face
		(03)	bridge abutment, sloped face
12.	Roadway over Bridge Structure	01	open gap between parallel bridges
		02	closed gap between parallel bridges
		(03)	rigid bridgerail—smooth and continuous construction
		(04)	semi-rigid bridgerail—smooth and continuous construction
		(05)	other bridgerail--probable penetration, snagging, pocketing or vaulting
		06	elevated gore abutment
13.	Retaining Wall	(01)	face
		02	exposed end
14.	Miscellaneous Point Hazards	(01)	pedestal base > 6 in. above ground, < 1 ft. diam.
		(02)	pedestal base > 6 in. above ground, > 1 ft. diam.
		(03)	historical monument < 1 ft. wide
		(04)	historical monument > 1 ft. wide

TABLE 5.1.12 SEVERITY INDICES

Identification Code	Descriptor Code	End Treatment Code Beginning	End Treatment Code Ending	Severity-Index
1. Utility Pole				
1	0	-	-	7.1
2. Trees				
2	0	-	-	8.0
3. Rigid Signpost				
3	1	-	-	4.7
3	2	-	-	7.2
3	3	-	-	7.2
3	4	-	-	7.2
3	5	-	-	8.1
4. Rigid Base Luminaire Support				
4	0	-	-	7.5
5. Curbs				
5	1	-	-	2.4
5	2	-	-	4.1
5	3	-	-	3.7
6. Guardrail or Median Barrier				
6	1	1	1	3.7
6	1	1	2	4.0
6	1	1	3	3.6
6	1	1	4	4.5
6	1	2	1	5.6
6	1	2	2	5.7
6	1	2	3	5.3
6	1	2	4	5.7
6	1	3	1	3.3
6	1	3	2	3.3
6	1	3	3	3.3
6	1	3	4	4.6
6	1	4	1	4.5
6	1	4	2	4.7
6	1	4	3	4.5
6	1	4	4	5.0
6	2	1	1	3.9
6	2	1	2	4.2
6	2	1	3	3.8
6	2	1	4	4.7
6	2	2	1	5.8
6	2	2	2	5.9
6	2	2	3	5.5
6	2	2	4	5.9
6	2	3	1	3.5
6	2	3	2	3.5
6	2	3	3	3.5
6	2	3	4	4.8
6	2	4	1	4.7
6	2	4	2	4.9
6	2	4	3	4.7
6	2	4	4	5.0
6	3	1	1	3.7
6	3	1	2	4.0
6	3	1	3	3.3
6	3	1	4	4.5
6	3	2	1	5.6
6	3	2	2	5.0
6	3	2	3	3.9
6	3	2	4	5.0
6	3	3	1	3.2
6	3	3	2	3.2
6	3	3	3	3.2
6	3	3	4	4.4
6	3	4	1	4.0
6	3	4	2	4.5
6	3	4	3	3.9
6	3	4	4	4.7
6	4	1	1	3.7
6	4	1	2	4.0
6	4	1	3	3.6
6	4	1	4	4.5
6	4	2	1	5.6
6	4	2	2	5.7
6	4	2	3	5.3
6	4	2	4	5.7
6	4	3	1	3.3
6	4	3	2	3.3
6	4	3	3	3.3
6	4	3	4	4.6
6	4	4	1	4.5
6	4	4	2	4.7

TABLE 5.1.12 SEVERITY INDICES (cont.)

Identification Code	Descriptor Code	End Treatment Code Beginning	End Treatment Code Ending	Severity-Index
6	4	4	3	4.5
6	4	4	4	5.0
6	5	1	1	3.9
6	5	1	2	3.9
6	5	1	3	3.9
6	5	1	4	3.9
6	5	2	1	3.9
6	5	2	2	3.9
6	5	2	3	3.9
6	5	2	4	3.9
6	5	3	1	3.9
6	5	3	2	3.9
6	5	3	3	3.9
6	5	3	4	3.9
6	5	4	1	3.9
6	5	4	2	3.9
6	5	4	3	3.9
6	5	4	4	3.9
6	6	1	1	4.4
6	6	1	2	4.4
6	6	1	3	4.4
6	6	1	4	5.0
6	6	2	1	5.6
6	6	2	2	5.7
6	6	2	3	5.3
6	6	2	4	5.7
6	6	3	1	4.0
6	6	3	2	4.4
6	6	3	3	4.0
6	6	3	4	4.6
6	6	4	1	4.5
6	6	4	2	4.7
6	6	4	3	4.5
6	6	4	4	5.0
6	7	1	1	4.2
6	7	1	2	4.2
6	7	1	3	4.2
6	7	1	4	4.2
6	7	2	1	4.2
6	7	2	2	4.2
6	7	2	3	4.2
6	7	2	4	4.2
6	7	3	1	4.2
6	7	3	2	4.2
6	7	3	3	4.2
6	7	3	4	4.2
6	7	4	1	4.2
6	7	4	2	4.2
6	7	4	3	4.2
6	7	4	4	4.2

Identification Code	Descriptor Code	End Treatment Code Beginning	End Treatment Code Ending	Severity-Index
7. Roadside Slope				
7	1	-	-	3.0
7	2	-	-	3.0
7	3	-	-	2.5
7	4	-	-	2.5
7	5	-	-	5.1
7	6	-	-	5.1
8. Ditch				
8	0	-	-	0.0
9. Culverts				
9	1	-	-	7.9
9	2	-	-	5.5
9	3	-	-	3.3
9	4	-	-	7.7
10. Inlets				
10	1	-	-	5.7
10	2	-	-	3.1
10	3	-	-	3.3
11. Roadway Under Bridge Structure				
11	1	-	-	9.3
11	2	-	-	9.3
11	3	-	-	2.5
12. Roadway Over Bridge Structure				
12	1	-	-	7.2
12	2	-	-	5.5
12	3	-	-	3.3
12	4	-	-	3.0
12	5	-	-	9.3
12	6	-	-	9.3
13. Retaining Wall				
13	1	-	-	3.3
13	2	-	-	9.3
14. Miscellaneous Point Hazards				
14	1	-	-	7.5
14	2	-	-	9.3
14	3	-	-	7.5
14	4	-	-	9.3

Metric Equivalent Equation

$$C = \frac{E_f}{2,000} [(L + 19.2) \cdot P[Y \geq A] + 5.14 \sum_{J=1}^{J=W} P[Y \geq A + 1.8 + \frac{2J - 1}{2}]]$$

E_f in Encroachments/km/yr

L, Y, A, and W in metres

(The width of J may be taken as 1 metre with the number of J units equal W rounded to the nearest whole number.)

This equation may be implemented directly into the cost analysis or used as a double-check for the collision frequency nomographs. Computation of the collision frequency for multiple objects requires special procedures.

6. Determine the initial cost of the obstacle, C_I. If it is already in place, its initial cost may be assumed to equal zero. For example, if a group of median bridge piers had been in existence for ten years, then the initial cost of a no improvement alternative would be taken to be zero. On the other hand, improvements to such a hazard would require initial expenditures which should be so designated.

7. Determine the average damage cost to the obstacle per accident, C_D (present dollars).

8. Determine the average maintenance cost per year, C_M, associated with the upkeep of the obstacle (present dollars).

9. Determine the average occupant injury and vehicle damage cost per accident, C_{OVD}, which would be expected as a result of a collision (present dollars). Table 5.1.12 and Figure 5.1.21 may be used to determine C_{OVD} in the absence of more definitive data. Direct interpolation of the cost table in Figure 5.1.21 is suggested to increase the accuracy of the estimate.

10. Determine the useful life, T, of the obstacle (years).

11. Determine the capital recovery and sinking fund factors. CRF and SF for the useful life. "T" and a current interest rate come from Tables 5.1.13 and 5.1.14.

12. Estimate the expected salvage value of the obstacle, C_S, at the end of its useful life (future dollars).

13. Calculate the total annual cost, C_{AT}, from the following equation:

$$C_{AT} = C_I\,[CRF] + C_D C_f + C_M + C_{OVD} C_f - C_S(SF)$$

or, to determine those costs which are directly incurred by the highway department (or implementing agency), (C_{A_D}), use the equation below:

$$C_{A_D} = C_I\,[CRF] + C_D C_f + C_M - C_S(SF)$$

These total annual costs represent an estimated value related to some appurtenance/barrier. Any number of locations or alternatives may be evaluated by utilizing this method, and a priority listing may be established. The alternative with the least total annual cost is the preferable alternative.

Summary of Variable Definitions

A = lateral placement of the roadside obstacle from EOP (feet) [metre]

L = horizontal length of the roadside obstacle (feet) [metre]

W = width of the roadside obstacle (feet) [metre]

ADT = average daily traffic (vehicles per day, two-way)

E_f = encroachment frequency (encroachments per mile per year) [encroachments per kilometre per year]

C_f = collision frequency (accidents per year)

SI = severity index

CI = initial cost of the obstacle (present dollars)

C_D = average damage cost per accident incurred to the obstacle (present dollars)

C_M = average maintenance cost per year for the obstacle (present dollars)

C_{OVD} = average occupant injury and vehicle damage cost per accident (present dollars)

C_S = estimated salvage value of the obstacle (future dollars)

C_{AT} = total present worth cost associated with the obstacle (dollars)

C_{AD} = total present worth direct cost associated with the obstacle (dollars)

CRF, SF = capital recovery and sinking fund factor for some current interest rate

TABLE 5.1.13 CAPITAL RECOVERY FACTORS (CRF)

Useful Life T (years)	Interest Rate i (Percent)												
	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
1	1.000	1.010	1.020	1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100	1.110	1.120
2	0.500	0.508	0.515	0.523	0.530	0.538	0.546	0.553	0.561	0.567	0.576	0.584	0.592
3	0.333	0.340	0.347	0.353	0.360	0.367	0.374	0.381	0.388	0.395	0.402	0.409	0.416
4	0.250	0.256	0.263	0.269	0.275	0.282	0.288	0.295	0.302	0.302	0.315	0.322	0.329
5	0.200	0.206	0.212	0.218	0.225	0.231	0.237	0.244	0.250	0.257	0.264	0.271	0.277
6	0.167	0.173	0.179	0.185	0.191	0.197	0.203	0.210	0.216	0.222	0.230	0.236	0.243
7	0.143	0.149	0.155	0.161	0.167	0.173	0.179	0.186	0.192	0.199	0.205	0.212	0.219
8	0.125	0.131	0.137	0.142	0.149	0.155	0.161	0.167	0.174	0.181	0.187	0.194	0.201
9	0.111	0.116	0.123	0.128	0.134	0.141	0.147	0.153	0.160	0.167	0.174	0.181	0.188
10	0.100	0.106	0.111	0.117	0.123	0.130	0.136	0.142	0.149	0.156	0.163	0.170	0.176
11	0.091	0.096	0.102	0.108	0.114	0.120	0.127	0.133	0.140	0.147	0.154	0.161	0.168
12	0.083	0.089	0.095	0.100	0.107	0.113	0.119	0.126	0.133	0.140	0.147	0.154	0.161
13	0.077	0.082	0.088	0.094	0.100	0.106	0.113	0.120	0.127	0.134	0.141	0.148	0.155
14	0.071	0.077	0.083	0.089	0.095	0.101	0.108	0.114	0.121	0.128	0.136	0.143	0.150
15	0.067	0.072	0.078	0.084	0.090	0.096	0.103	0.110	0.117	0.124	0.131	0.139	0.147
16	0.063	0.068	0.074	0.080	0.086	0.092	0.099	0.106	0.113	0.120	0.128	0.136	0.143
17	0.059	0.064	0.070	0.076	0.082	0.089	0.095	0.102	0.110	0.117	0.125	0.132	0.140
18	0.056	0.061	0.067	0.073	0.079	0.086	0.092	0.099	0.107	0.114	0.122	0.130	0.137
19	0.053	0.058	0.064	0.069	0.076	0.083	0.090	0.097	0.104	0.112	0.120	0.128	0.136
20	0.050	0.055	0.061	0.067	0.074	0.080	0.087	0.094	0.102	0.110	0.117	0.126	0.134
21	0.048	0.053	0.059	0.065	0.071	0.078	0.085	0.092	0.100	0.108	0.116	0.124	0.132
22	0.045	0.051	0.057	0.063	0.069	0.076	0.083	0.090	0.098	0.106	0.114	0.122	0.130
23	0.043	0.049	0.055	0.061	0.067	0.074	0.081	0.089	0.096	0.104	0.113	0.121	0.129
24	0.042	0.047	0.053	0.059	0.066	0.072	0.080	0.087	0.095	0.103	0.111	0.120	0.128
25	0.040	0.045	0.051	0.057	0.064	0.071	0.078	0.086	0.094	0.102	0.110	0.118	0.127
26	0.038	0.044	0.050	0.056	0.063	0.070	0.077	0.085	0.093	0.101	0.109	0.118	0.127
27	0.037	0.042	0.048	0.055	0.061	0.068	0.076	0.083	0.091	0.100	0.108	0.117	0.126
28	0.036	0.041	0.047	0.053	0.060	0.067	0.075	0.082	0.090	0.099	0.107	0.116	0.125
29	0.034	0.040	0.046	0.052	0.059	0.066	0.074	0.081	0.090	0.098	0.106	0.115	0.125
30	0.033	0.039	0.045	0.051	0.058	0.065	0.073	0.081	0.089	0.097	0.106	0.115	0.124

TABLE 5.1.14 SINKING FUND FACTOR (SF)

Useful Life T (years)	Interest Rate i (Percent)												
	0.1	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.500	0.498	0.495	0.493	0.490	0.488	0.486	0.483	0.481	0.477	0.476	0.474	0.472
3	0.333	0.330	0.327	0.323	0.320	0.317	0.314	0.311	0.308	0.305	0.302	0.299	0.296
4	0.250	0.246	0.243	0.239	0.235	0.232	0.228	0.225	0.222	0.219	0.215	0.212	0.209
5	0.200	0.196	0.192	0.188	0.185	0.181	0.177	0.174	0.170	0.167	0.164	0.161	0.157
6	0.167	0.163	0.159	0.155	0.151	0.147	0.143	0.140	0.136	0.132	0.130	0.126	0.123
7	0.143	0.139	0.135	0.131	0.127	0.123	0.119	0.116	0.112	0.109	0.105	0.102	0.099
8	0.125	0.121	0.117	0.112	0.109	0.105	0.101	0.097	0.094	0.091	0.087	0.084	0.081
9	0.111	0.106	0.103	0.098	0.094	0.091	0.087	0.083	0.080	0.077	0.074	0.071	0.068
10	0.100	0.096	0.091	0.087	0.083	0.080	0.076	0.072	0.069	0.066	0.063	0.060	0.056
11	0.091	0.086	0.082	0.078	0.074	0.070	0.067	0.063	0.060	0.057	0.054	0.051	0.048
12	0.083	0.079	0.075	0.070	0.067	0.063	0.059	0.056	0.053	0.050	0.047	0.044	0.041
13	0.077	0.072	0.068	0.064	0.060	0.056	0.053	0.050	0.047	0.044	0.041	0.038	0.035
14	0.071	0.067	0.063	0.059	0.055	0.051	0.048	0.044	0.041	0.038	0.036	0.033	0.030
15	0.067	0.062	0.058	0.054	0.050	0.046	0.043	0.040	0.037	0.034	0.031	0.029	0.027
16	0.063	0.058	0.054	0.050	0.046	0.042	0.039	0.036	0.033	0.030	0.028	0.026	0.023
17	0.059	0.054	0.050	0.046	0.042	0.039	0.035	0.032	0.030	0.027	0.025	0.022	0.020
18	0.056	0.051	0.047	0.043	0.039	0.036	0.032	0.029	0.027	0.024	0.022	0.020	0.017
19	0.053	0.048	0.044	0.039	0.036	0.033	0.030	0.027	0.024	0.022	0.020	0.018	0.016
20	0.050	0.045	0.041	0.037	0.034	0.030	0.027	0.024	0.022	0.020	0.017	0.016	0.014
21	0.048	0.043	0.039	0.035	0.031	0.028	0.025	0.022	0.020	0.018	0.016	0.014	0.012
22	0.045	0.041	0.037	0.033	0.029	0.026	0.023	0.020	0.018	0.016	0.014	0.012	0.010
23	0.043	0.039	0.035	0.031	0.027	0.024	0.021	0.019	0.016	0.014	0.013	0.011	0.009
24	0.042	0.037	0.033	0.029	0.026	0.022	0.020	0.017	0.015	0.013	0.011	0.010	0.008
25	0.040	0.035	0.031	0.027	0.024	0.021	0.018	0.016	0.014	0.012	0.010	0.008	0.007
26	0.038	0.034	0.030	0.026	0.023	0.020	0.017	0.015	0.013	0.011	0.009	0.118	0.007
27	0.037	0.032	0.028	0.025	0.021	0.018	0.016	0.013	0.011	0.010	0.008	0.117	0.006
28	0.036	0.031	0.027	0.023	0.020	0.017	0.015	0.012	0.010	0.009	0.007	0.116	0.005
29	0.034	0.030	0.026	0.022	0.019	0.016	0.014	0.011	0.010	0.008	0.006	0.115	0.005
30	0.033	0.029	0.025	0.021	0.018	0.015	0.013	0.011	0.009	0.007	0.006	0.115	0.004

5.1.53 Example 1 - Roadside Slope

In the first example, it is desired that criteria be established to indicate when it is cost-effective, in terms of ADT and side-slope, to shield an embankment. It is assumed that an operating speed of approximately 60 mph (96.6 km/hr) exists. The general geometry of the roadside is illustrated in Figure 5.1.22. For purposes of analysis, both the average daily traffic, ADT, and the roadside slope will be considered as variables. Values assigned to other variables are assumed to fall within a reasonable expected range. The following analysis will consider shielding with a roadside barrier first and then the alternative of no shielding.

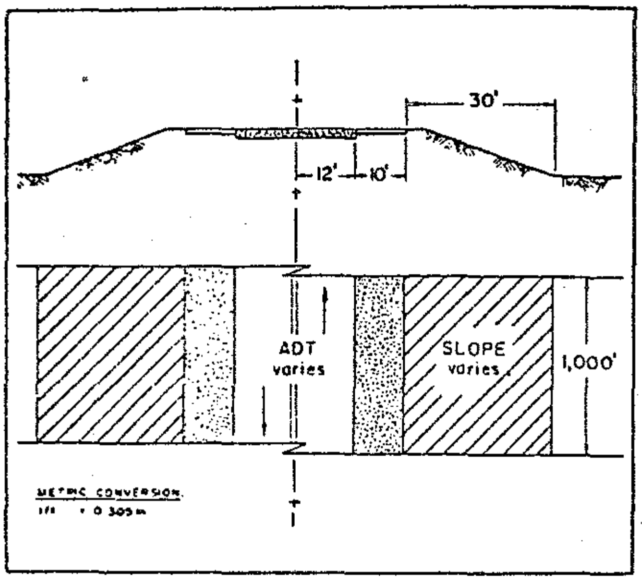


Figure 5.1.22 Roadside Slope Geometry

Roadside Barrier

Before this alternative can be considered in the cost-effectiveness procedure, the flared end-treatment geometry should be established by implementing the barrier flare criteria set forth in Section 5.1.44. On the basis of these criteria, the flared sections were assumed to exhibit the following general geometry:

- The average offset equals 15 ft (4.6 m).
- The horizontal length of the flared sections equals 256 ft (78.0 m).
- And the total rail length needed equals 257 ft (78.4 m).

These lengths represent the total length of need of the flared section plus a breakaway cable terminal treatment.

In continuing, the roadside barrier analysis involves two distinct computations. In the first case, costs associated with the flared portion of the barrier are computed. Then, costs associated with the barrier proper or the tangent section are computed. The two are then combined to determine the total cost. However, a minor adjustment must be made in determining the collision frequency since the flared portion and the barrier proper are joined at a common point. The following general rule applies in this and other such cases:

For two objects joined together, use the actual length (L) of the object with the highest severity index (SI) and subtract 31.4 (9.6 for metric equivalent) from the length of the other object when determining their respective collision frequencies.

This rule is illustrated in the following example. Note that the cost determination steps follow the format previously outlined.

Flared End Treatment

1. A = 15 ft (4.6 m)

   L = 256 ft (78.0 m)

   W = 1 ft (.305 m) (rail width)

2. ADT = 10,000 (assumed)

3. E_f = 3.2

4. C_f = 0.078 (Actual length is used to determine C_f because SI for flared section is higher than for barrier proper.)

5. Code 06-01-1; SI = 3.7

6. C_I = $13.00 (assumed) per foot at 257 ft (78.39 m)

   C_I = $3,341

7. C_D = $225

8. C_M = $1.50 per foot per year (assumed) at 257 ft (78.4 m);

   C_M = $386

9. C_{OVD} = $7,192 at SI = 3.7 (Figure 5.1.21)

10. T = 15 years

11. CRF = 0.117

    at an assumed rate of 8%

    SF = 0.037

12. C_S = $3.00 per foot (assumed) at 257 ft (78.4 m)

    C_S = $771

13. CA_T = 3341 (0.117) + 225 (0.078) + 386 + 7192 (0.078) - 771 (0.037)

CA_T = $1,327

CA_D = 3341 (0.117) + 225 (0.078) + 386 - 771 (0.037)

CA_D = $766

Barrier Proper

1. A = 10 ft (3.05 m)

L = 1000 ft (305 m)

W = 1 ft (.31 m)

2. ADT = 10,000

3. E_f = 3.2

4. C_f = 0.29 based on L - 31.4 or 968.6 ft (295 m) (See Example 1)

5. Code 06-01-3-2; SI = 3.3 (See Table 5.1.10)

6. C_I = $13.00 per foot (assumed) at 1000 ft (305 m);

C_I = $13,000

7. C_D = $225 (assumed)

8. C_M = $1.50 per foot per year (assumed) at 1000 ft (305 m);

C_M = $1,500

9. C_{OVD} = $5,874 at SI = 3.3

10. T = 15 years

11. i = 8%

CRF = 0.117

SF = 0.037

12. C_S = $3.00 per foot (assumed at 1,000 ft (305 m);

C_S = $3,000

13. C_{A_T} = 13000 (0.117) + 225 (0.29) + 1500 + 5874 (0.29) - 3000 (0.037)

= 1521 + 65 + 1500 + 1703 - 111

C_{A_T} = $4,678

C_{A_T} = $2,975

TOTAL C_{A_T} = 1327 + 4678 = $6,005

TOTAL C_{A_D} = 766 + 2975 = $3,741

These two total costs represent values associated with an average daily traffic equaling 10,000 vehicles per day. The above steps are repeated for higher values of ADT until enough data points are determined to plot CA_T versus ADT. Ultimately, the total barrier values as a function of average daily traffic will be used in the alternative comparison.

Unprotected Slopes

Another alternative which should be considered involves no shielding at all. This alternative requires no direct expenditures since it is assumed that the problem involves existing roadways. Consequently, only the total costs (to include occupant and vehicle damage) can significantly indicate the benefits/disbenefits associated with no shielding of the embankment.

For purposes of analysis, four slopes have been considered as variables in addition to the average daily traffic control. These slopes and their respective estimated severities for assumed site conditions are as follows:

- (3.5:1) slope - severity index equals 3.5
- (3:1) slope - severity index equals 4.0
- (2.5:1) slope - severity index equals 4.5, and
- (2:1) slope - severity index equals 5.0

(Note that for fills steeper than about 3:1 the height of fill should be expected to influence severity.)

Although the slope severities are not specifically identified in the hazard inventory information, a severity index is listed for a negative slope. Assuming that this negative slope represents an average situation and that a 4:1 slope is approximately average, then the severity index of a 4:1 slope would be found to equal 3.0. Furthermore, since the severity index of the roadside barrier is greater than that of the 4:1 slope, then in no way can the barrier be more cost-effective. By taking the average slope as a base, the severities of the other gradients were estimated, and occupant and vehicle damage costs were assigned. The initial, damage, maintenance, and salvage costs were all taken to be zero since it is assumed that the existing geometry requires no direct expenditures. By choosing the average daily traffic again to equal 10,000 vehicles per day and considering a 3.5:1 slope, the costs may be determined by the following steps:

1. $A = 10$ ft (3.05 m)

$L = 1{,}000$ ft (305 m)

$W = 30$ ft (9.15 m)

2. $ADT = 10{,}000$

3. $E_f = 3.2$

4. $C_f = 0.30$

5. $SI = 3.5$

6. $C_I = \$0$

7. $C_D = \$0$

8. $C_M = \$0$

9. $C_{OVD} = \$6{,}533$ at $SI = 3.5$

10. $T = 15$ years

11. $CRF = 0.117$, $SF = 0.037$ } at an assumed interest rate of 8%

12. $C_S = \$0$

13. $C_{A_T} = 0 + 0 + 0 + 6535\ (0.30) - 0$

$= \$9{,}961$

$C_{A_D} = \$0$

Total costs for the four slopes and varying volumes are calculated in a similar manner to provide the basis of comparison for the no protection alternative.

Comparison

The various situations can best be compared by plotting curves of total present cost versus average daily traffic. Such a set of curves is shown in Figure 5.1.23. By interpreting the data the following conclusions may be drawn:

1. Unprotected slopes of 3:1 and flatter are more cost-effective than the barrier for an average daily traffic up to and in excess of 50,000 vehicles per day; i.e., the barrier is not warranted;

2. The 2.5:1 slope, unprotected, (assumed severity 4.5) becomes less cost-effective than the barrier for an average daily traffic equal to or above 12,000 vehicles per day; and

3. The 2:1 slope, unprotected, (assumed severity 5.0) becomes less cost-effective than the barrier for an average daily traffic equal to or above 10,000 vehicles per day.

This analysis serves to provide some insight as to where roadside barrier protection of slopes may or may not be more cost-effective. General design guidelines or policies may be established and, more importantly, justified in terms of the highest returns in safety.

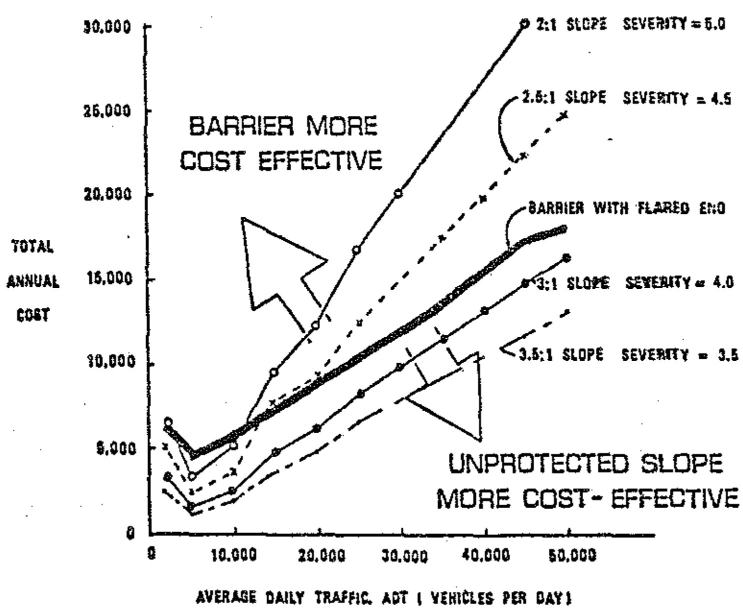


Figure 5.1-23 Cost Comparison Curves

General Comments

1. The analysis, as presented in this problem, involves only those costs associated with one side of the highway facility. If the same conditions exist on the opposite side, then the total costs for both sides would be double those previously determined.

2. The average daily traffic should represent the two-way volume flow since the volume split is built into the analysis procedure. This adjustment is effected by the collision frequency nomographs.

3. The useful life of a roadside slope is taken to be 15 years, which is obviously not the real case. However, there is little difference in the economic factors beyond 15 years.

4. This example illustrates how the procedure can be used to determine the cost-effectiveness of two basic options, i.e., barrier shielding versus no shielding of slopes, for a given location. Although not considered here, the next desirable step may be to establish a priority or ranking system for reducing hazards within a given roadway system. The objective would be to make improvements that offer the greatest return in terms of safety. The following equation may be used for determining a ranking factor, R:

$$R = \frac{C_{A_H} - C_{A_I}}{C_{A_{D_I}}}$$

where

C_{A_H} = annual cost associated with the unshielded hazard over the period T;

C_{A_I} = annual cost associated with the improvement over the period T; and

$C_{A_{D_I}}$ = annual cost to the highway department or agency associated with the improvement.

Improvements should be made to those hazards having the highest value R first. Note that if the numerator is negative, the improvement would not be cost-effective. In Example 1, the ranking factor for placing a roadside barrier to shield the 2:1 slope (assumed severity 5.0) for an ADT of 25,000 would be computed as follows:

C_{A_H} = \$16,710 (Slope) (From Figure 5.1.21)

C_{A_I} = \$10,612 (Barrier) (From Figure 5.1.21)

$C_{A_{D_I}}$ = \$3,530 (From previous calculations)

thus

$$R = \frac{16{,}710 - 10{,}612}{3{,}530}$$

or

$$R = 1.7$$

5.1.54 Example 2 - Bridge Piers

Figure 5.1.24 shows a typical bridge pier hazard. Three alternatives will be considered in the cost analysis as follows:

1. No protection of the bridge piers

2. Protection of the bridge piers with a roadside barrier rail

3. Protection of the bridge piers with a combination roadside barrier rail and crash cushion system

Subsequent to the cost calculations, a comparison of the three operations will be made based on a present worth basis, and the most cost-effective design will be identified. Note that the steps in the analysis correspond to those described in the introduction of the section above.

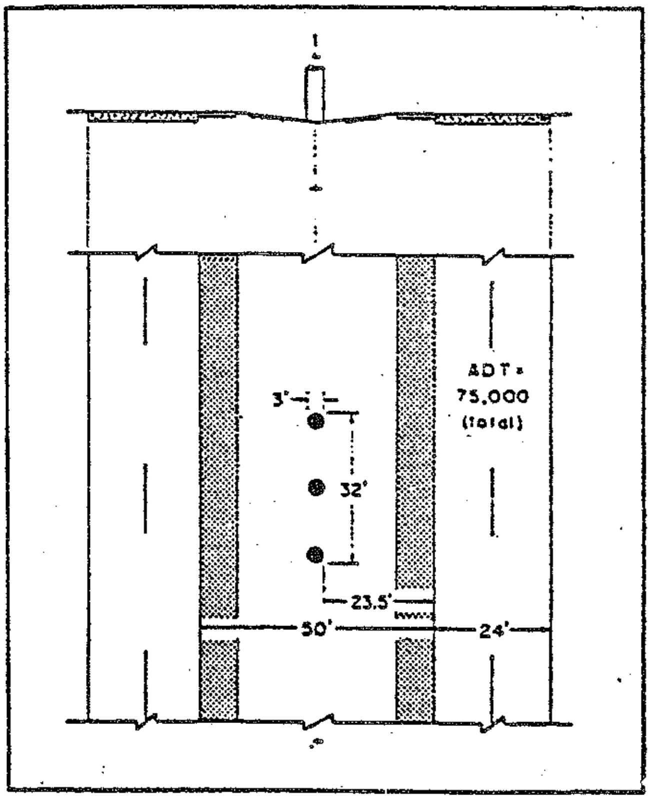


Figure 5.1.24 Bridge Pier Hazard

No Protection

1. A = 23.5 ft (7.17 m) or approximately 23 ft (7.02 m);

   L = 32 ft (9.75 m) and:

   W = 3 ft (.92 m)

2. ADT = 75,000 (assumed)

3. E_f = 31.0

4. C_f = 0.17

5. Code -01; SI = 9.3 (See Table 5.1.10)

6. C_I = $0 (since the piers are existing)

7. C_D = $0 (assumed)

8. C_M = $0 (assumed)

9. C_{OVD} = $169.340 at SI = 9.3

10. T = 20 years

11. CRF = 0.102 } at an interest rate of 8%

12. SF = 0.022 }

    C_S = $0

13. C_{A_T} = 0 (.102) + 0 (0.17) + 0 + 169.340 (0.102) - 0 (0.022)

    = $17,273

    C_{A_D} = $0

or considering collisions with both ends of the bridge pier hazard,

C_{A_T} = $34,545

C_{A_D} = $0

These figures represent the present costs associated with no protection to the roadway hazard. The total cost, as would be expected, is quite substantial due to the severity associated with impacting a fixed bridge pier, while the total direct cost is zero since no improvements are involved. Although the existing geometry may not offer the best alternative, it must be calculated for use as a basis in comparison.

Roadside Barrier

Before the cost analysis can be implemented for this option, specific attention needs to be directed toward identifying the barrier flare geometry. From the barrier flare criteria outlined previously, (See Section 5.1.44) the placement values to be used in the cost procedure were assumed to be the following:

1. The average offset for the flared sections equals 16 ft (4.88 m)

2. The projected longitudinal length of the barrier flare equals 151 ft (46.01 m)

3. The actual length of the barrier flare equals 153 ft (46.67 m).

In determining the total costs associated with roadside barrier protection, two separate calculations will be made - one considering collisions with the barrier flare and the other involving impacts to the barrier proper. The sum of these two costs will represent the total value associated with the roadside barrier alternative. Note that costs for one direction of travel are computed, then doubled, to obtain costs for both directions of travel. It is assumed that a crashworthy end treatment is used at the upstream terminal.

Barrier Flare

1. A = 16 ft (4.88 m),

   L = 151 ft (46.01 m)

   W = 1 ft (.31 m)

2. ADT = 75,000

3. E_f = 31.0

4. C_f = 0.52 (Actual length is used to determine C_f, because SI for flared section is higher than for barrier proper.)

5. Code 06-01-1-1 SI = 3.7 (Table 5.1.10)

6. C_I = $13.00 per foot (assumed) at 153 ft (46.67 m), thus

   C_I = $1,989

7. C_D = $225 (assumed)

8. C_M = $1.50 per foot per year (assumed) at 153 ft (46.67 m);

   C_M = $230

9. C_{OVD} = $7,192 at SI = 3.7

10. T = 20 years

11. CRF = 0.102 } at 8%

    SF = 0.022 }

12. C_S = $1.50 per foot (assumed) at 153 ft (46.67 m)

    C_S = $230

13. C_{A_T} = 1989 (0.102) + 225 (0.52) + 203 + 7192 (0.52) - 230 (0.022)

= $4,285

C_{A_D} = $545

Barrier Proper

1. A = 13.5 ft (4.12 m);

L = 32 ft (9.76 m); and

2. ADT = 75,000

3. E_f = 31.0

4. C_f = .17 Based on L - 31.4 = 0.6 ft (0.2 m) (See rule in Section 5.1.52.)

5. Code 06-01-3-2 SI = 3.3 (Appendix E)

6. C_I = $13.00 per foot (assumed) at 32 ft (4.12 m); thus, C_I = $416

7. C_D = $225 (assumed)

8. C_M = $1.50 per foot per year (assumed) at 32 ft (4.12 m); thus

C_M = $48

9. C_{OVD} = $5,874 at SI = 3.3

10. T = 20 years

11. CRF = 0.102

SF = 0.022

12. C_S = $1.50 per foot (assumed) at 32 ft (4.12 m); thus C_S = $48

13. C_{A_T} = 416 (0.102) + 225 (0.17) - 48 + 5874 (0.17) - 48 (0.022)

= $1,078

C_{A_D} = $79

The total barrier costs may now be found by totaling the values for the flare and the barrier proper. Furthermore, the total amounts considering shielding for both sides may be attained by doubling the costs associated with collisions from one side.

Therefore, for protection to one end:

Total C_{A_T} = 4285 + 1078 = $5,363

Total C_{A_D} = 545 + 79 = $624

for protection of both ends:

Total C_{A_T} = $10,726

Total C_{A_D} = $1,248

Roadside Barrier/Crash Cushion System

The third alternative considered in the bridge pier analysis will be an integrated crash cushion - longitudinal barrier system. The crash cushion will be utilized as an end treatment to shield the end piers and the ends of the roadside barrier. The roadside barrier is placed along the 32 foot length (9.8 m) to shield the interior pier. Costs for each of the subsystems may be determined given their respective geometrics, and a total present worth may be fixed.

Crash Cushion - End Treatment

1. A = 21 ft (6.4 m),

L = 25 ft (7.6 m),

W = 8 ft (2.4 m)

2. ADT = 75,000 (assumed)

3. E_f = 31.0

4. C_f = 0.12 Based on L - 31.4 = -6.4 ft (-2.0 m) (See rule in Section 5.1.53)

5. Code 15-00-0-0 SI = 1.0 (Table 5.1.10)

6. C_I = $5,000 (assumed)

7. C_D = $1,000 (assumed)

8. C_M = $150 (assumed)

9. C_{OVD} = $2,095 at SI = 1.0

10. T = 20 years

11. CRF = 0.102 } at an assumed interest rate of 8%

SF = 0.022

12. C_S = 0.0

13. C_{A_T} = (5000) (0.102) + 1000 (0.12) + 150 + 2095 (0.12) - 0 (.022)

= $1,031

C_{A_D} = $780

Roadside Barrier

1. A = 21 ft (6.4 m),

L = 32 ft (9.8 m),

W = 1 ft (0.305 m)

2. ADT = 75,000

3. E_f = 31.0

4. C_f = 0.19 (Actual length is used to determine C_f because SI for roadside barrier is higher than for crash cushion.)

5. Code 06-01-3-3 SI = 3.3 (Table 5.1.10)

6. C_I = \$13.00 per foot (assumed) at 32 ft (9.8 m); thus C_I = \$416

7. C_D = \$225 (assumed)

8. C_M = \$1.50 per foot per year (assumed) at 32 ft (9.8 m); thus,

C_M = \$48

9. C_{OVD} = \$5,874 at SI = 3.3

10. T = 20 years

11. CRF = 0.102, SF = 0.022 } at an assumed interest rate of 8%

12. C_S = \$1.50 per foot (assumed) at 32 ft (9.8 m); thus C_S = \$48

13. C_{A_T} = 416 (0.102) + 225 (0.19) + 48 + 5874 (0.19) - 48 (0.022)

= \$1,248

C_{A_D} = \$132

Considering both the costs for the attenuator and the longitudinal barrier, the total system present worth values may be compared as follows:

For protection of one end:

Total C_{A_T} = 1031 + 1248 = \$2,279

Total C_{A_D} = 780 + 132 = \$912

and for shielding for both sides:

Total C_{A_T} = 2 (2279) = \$4,558

Total C_{A_D} = 2 (912) = \$1,824

Comparison

Table 5.1.15 summarizes the results of this example. By collectively reviewing the three proposed alternatives, several observations and conclusions may be outlined. However, the significance of these observations must be weighed in light of the assumptions made and the values assigned to the various parameters. While these values are thought to be typical, they may not be representative of all areas.

1. While the no shielding alternative requires no direct expenditures, it does represent a very substantial total annual cost in terms of accident losses.

2. On an annual cost basis, the roadside barrier/crash cushion system offers the best alternative. However, it does require a somewhat higher direct expenditure.

3. The ranking factor indicates that of the two improvements, the roadside barrier would provide the greatest return per dollar spent.

TABLE 5.1.15 EXAMPLE COMPARISON

OPTION	Direct Annual Cost, C_{A_D} (\$)	Total Annual Cost, C_{A_T} (\$)	Ranking Factor, R
1. No Shielding	0	\$34,545	--
2. Shielding by Roadside Barrier	\$1,248	\$10,726	19.1
3. Shielding by Crash Cushion/ Roadside Barrier	\$1,824	\$ 4,558	16.4

General Comments

1. Practically speaking, the main interest in comparing alternatives two, and three is to objectively decide whether the shorter, more expensive and less severe crash cushion would/would not enjoy an advantage over the longer, lower cost and higher severity barrier rail.

2. The main purpose of this example is to demonstrate the use of the cost-effectiveness approach in weighing several alternative solutions for one problem location. Other roadside hazard locations may be evaluated in a similar manner to organize a complete facility inventory and a set of ranking factors.

5.1.55 Example 3 - Elevated Gore Abutment

In this example, an elevated gore abutment has been chosen for analysis, and both costs for the hazard and an improvement will be determined. By referencing the layout shown in Figure 5.1.25, those inputs necessary for the calculations may be obtained, and the procedure may be initiated. Also, higher than normal encroachments that are common to such a location will be considered in the analysis, and adjustments will be made accordingly. Furthermore, the evaluation will consider only collisions with the exposed gore and crash cushion, whichever the case may be. Also, the equation for C_f will be applied in lieu of the nomographs to demonstrate its use.

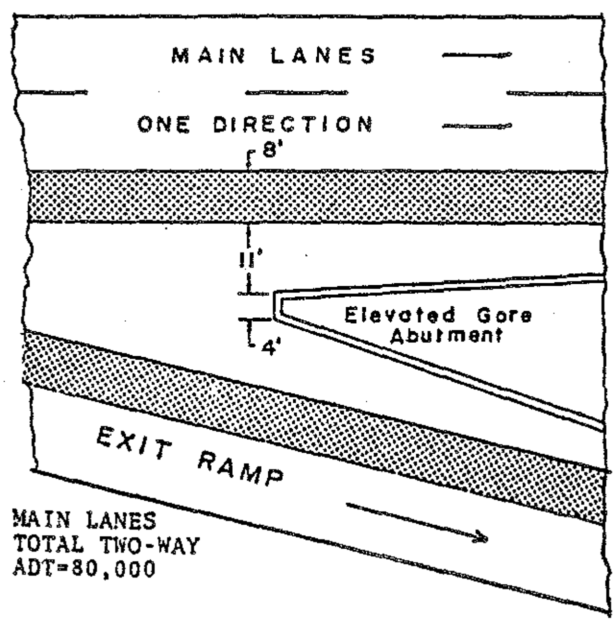


Figure 5.1.25 Elevated Gore Abutment

Existing Hazard

1. $A = 19$ ft (5.8 m);

   $L = 1$ ft (.305 m); and

   $W = 4$ ft (1.2 m)

2. ADT = 80,000

3. $E_f = 33.5$

4. C_f by using equation may be determined as below:

$$C_f = \frac{33.5}{10,560} (1 + 62.9) (.73) + 5.14 (0.455 + 0.405 + 0.360 + 0.325)$$

$C_f = 0.17$ and by applying an adjustment factor of 3.0 for higher than normal encroachments (assumed),

C_f (adjusted) = 3 (0.17) = 0.52

5. Code 12-06-0-0 SI = 9.3 (Table 5.1.10)

6. $C_I = \$0$

7. $C_D = \$0$ (assumed)

8. $C_M = \$0$ (assumed)

9. $C_{OVD} = \$169,412$ at SI = 9.3

10. T = 15 years

11. CRF = 0.117, SF = 0.037 } at an assumed interest rate of 8%

12. $C_S = \$0$

13. $C_{A_T} = 0 (0.117) + 0 (0.52) + 0 + \$169,412 (0.52) - 0 (0.037)$

    $= \$88,094$

    $C_{A_D} = \$0$

Crash Cushion Improvement

1. $A = 17$ ft (5.2 m);

   $L = 25$ ft (7.6 m); and

   $W = 8$ ft (2.4 m)

2. ADT = 80,000

3. $E_f = 33.5$

4. C_f by using the equation may be determined as below:

$$C_f = \frac{33.5}{10,560} (25 + 62.9) (0.79) + 5.14 (0.550 + 0.505 + 0.455 + 0.405 + 0.360 + 0.320 + 0.290 + 0.260)$$

C_f = 0.27 and by applying an adjustment factor of 3.0 for higher than normal encroachments (assumed)

C_f (adjusted) = 3 (0.27) = 0.81.

5. Code 15-00-0-0 SI 1.0 (Table 5.1.10)
6. C_I = \$5,000 (assumed)
7. C_D = \$1,000 (assumed)
8. C_M = \$200 (assumed)
9. C_{OVD} = \$2,095 at SI = 1.0
10. T = 15 years
11. CRF = 0.117, SF = 0.037 } at an assumed interest rate of 8%
12. C_S = \$0 (assumed)
13. C_{A_T} = 5000 (0.117) + 1000 (0.81) + 200 + 2095 (0.81) - 0 (0.037)

    = \$3,292

    C_{A_D} = \$1,595

By comparing the total costs related to each of the two situations, it may be seen that from a safety standpoint the advantage obviously lies with the improvement alternative. The ranking factor for this site would be 53 which further points out the benefits, in terms of increased safety, that can be realized by installing a crash cushion at such a zone.

In those locations where the traffic-geometric relationships become critical, the collision frequency may be adjusted upward at the discretion of the designer. A factor of 3.0 has been proposed for gore areas, and this seems to be a legitimate number; however, in locations where the variables are not so critical, possibly a lower factor would be appropriate. The decision on such an adjustment would rely strictly on the user's knowledge of the field and his engineering judgment.

5.1.56 Example 4 - Isolated Roadside Obstacles

As has been emphasized throughout this section, the most desirable roadside is one that is relatively flat and free of roadside hazards. If ample recovery room is provided, a driver of an errant vehicle will be able to return to the traveled way or safely stop the vehicle. Removal or relocation of hazards, or the installation of a breakaway device should always be the first option considered. However, various situations may sometimes dictate that isolated obstacles such as small trees or small utility poles be located within the desirable recovery area. In such cases, the designer often is faced with the question: Should the obstacle be shielded by a barrier, even though it is obvious that the hazard potential of the barrier is less than the obstacle? The following example illustrates how this question can be answered by the cost-effectiveness procedure.

Existing Hazard - No Protection

Assume that the existing hazard conditions are the same as those in Example 2 except that instead of three bridge piers the obstacles are three small trees located on the roadside instead of the median. All of the parameters defined under no protection of Example 2 therefore apply here,[1] with one exception and that is the SI of the trees which is assumed as 5.0. It will be further assumed that the SI of the trees does not change over the 20-year period. Should this not be the case, the procedure presented herein would not be applicable. Selection of an SI for such obstacles must be based primarily on engineering judgment due to an absence of objective criteria. From Figure 5.1.21:

C_{OVD} = \$16,710

Thus,

C_{A_T} = 16,710 (0.102)

C_{A_T} = \$1704

and

C_{A_D} = \$0

Protection by Roadside Barrier

All of the parameters from the Example 2 Roadside Barrier Section apply here.

Thus,

C_{A_T} = \$10,726

and

C_{A_D} = \$1,248

Comparison

The most cost-effective alternative in this case is to leave the trees unshielded (assuming they cannot be removed) since the numerator of the ranking equation "R" is negative. Although the trees would have a greater hazard potential per accident, the considerably greater target area of the barrier and its closer proximity to the traveled way would result in considerably more barrier impacts than tree impacts. However, as the length of the line of trees increases, the difference in the cost of the two alternatives decreases. At some length of unshielded trees the barrier would become more cost effective. The reader should also remember that the size of the tree is very signigicant in this analysis. Repeated solutions similar to the one above for different lengths of unshielded trees will reveal the break-even point where the barrier will be cost-effective.

REFERENCES

1. AASHTO, Guide For Selecting, Locating and Designing Traffic Barriers, 1977.

2. Weaver, Graeme D. and D.L. Woods. Cost-Effectiveness Evaluation of Roadside Safety Improvements on Texas Highways. Research Report 15-2F, Texas Transportation Institute, 1976.

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