Research Report
KTC-89-39

# WARRANTS AND GUIDELINES FOR INSTALLATION OF GUARDRAIL

by

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Transportation Cabinet
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and

Federal Highway Administration
US Department of Transportation



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COMMONWEALTH OF KENTUCKY
TRANSPORTATION CABINET
FRANKFORT, KENTUCKY 40622

MILO D. BRYANT
SECRETARY
AND
COMMISSIONER OF HIGHWAYS

WALLACE G. WILKINSON
GOVERNOR

May 17, 1990

Mr. Paul E. Toussaint
Division Administrator
Federal Highway Administration
330 West Broadway
Frankfort, Kentucky 40601

Dear Mr. Toussaint:

SUBJECT: IMPLEMENTATION STATEMENT
Research Study, "Standards and Guidelines for Guardrail Installations on Existing Highways," (KYHPR 88-124)

The primary result from this study is a procedure to identify and prioritize existing highway sections in need of guardrail. A procedure is documented that will permit implementation of Kentucky's policy of an annual Guardrail Improvement Program, including a cost-effectiveness ranking for each location built upon a statewide inventory. From an initial selection of locations with critical numbers and rates of run-off-road accidents, and other known hazardous sites previously identified, a field survey will be performed to catalog operational and cross-section characteristics for input into a hazard-index point system. When guardrail is the only practical improvement alternative, needs will be determined based on a comparison of cross-section characteristics and warranting criteria developed for clear zones and embankments. Whether guardrail or other alternatives are considered, the procedures documented in the study will be used to determine improvement priorities based on cost-effectiveness and budget optimization.

Where site specific engineering analyses indicate that the w-beam, blocked-out guardrail is not practical, consideration will be given to a weak-post system as presented in the AASHTO "Roadside Design Guide." Box beam and cable systems will not be considered due to parts incompatibility with existing guardrail systems.

The implementation of the study recommendations are applicable only to maintenance activities and new installations of guardrail on existing roadways. Guardrail standards for new construction and for reconstruction, rehabilitation and restoration are not affected.

Sincerely,

O. G. Newman, P. E.
State Highway Engineer

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16. Abstract

Kentucky, as most other states, has in the past relied on the AASHTO "Barrier Guide" for guidance in the installation of guardrail. Additional information related to barrier selection and installation was recently published in the form of the AASHTO "Roadside Design Guide." However, considerable judgement is required for application of this information and it was determined that significant benefit could be derived from development of guidelines representative of conditions in Kentucky. Listed below are significant results from this study.

1. Results from a previous survey of guardrail standards and guidelines were summarized and it was found that only a few states suggested use of reduced guardrail standards.
2. Warranting guidelines for clear zones and embankments based on Kentucky accident severities and costs were developed from a computer program included as part of the "Roadside Design Guide."
3. For low service level roads, several operational barrier systems were recommended for consideration when the W-beam, blocked-out guardrail is found to be impractical due to geometric, terrain, or cost constraints.
4. A procedure was developed to identify and prioritize highway sections in need of guardrail based on determining locations with critical numbers and rates of run-off-road accidents, conducting a field survey to tabulate hazard-index points, and performing a cost-effectiveness analysis.

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## INTRODUCTION

Kentucky, as most other states, has in the past relied on the AASHTO publication titled "Guide for Selecting, Locating, and Designing Traffic Barriers," (1) for guidance in the installation of guardrail. However, there are geometric constraints on existing roads that do not permit use of the AASHTO guidelines in many cases. In addition, there are other issues to be addressed when outdated guardrail sections or end treatments are damaged and in need of repair. Frequently it is impractical to install guardrail to meet current standards without major reconstruction.

It appears that there are many miles of roadway in Kentucky that would meet the general requirements for roadside barriers based on fill height and slope and clear zones; however, the cost-effectiveness of guardrail is questionable without more detailed analysis. Presently, there is no program within the Department of Highways to identify and prioritize locations where guardrails are needed. A cost-effective selection procedure was presented in the AASHTO "Barrier Guide" (1). However, the procedure is relatively complicated and the data requirements make it difficult to use on a system-wide basis.

Another issue related to guardrails is the maintenance of proper guardrail height. The current standard for W-Beam guardrail with standard metal or wood post is 27 inches. Adequate height must be maintained in order to ensure proper performance when the guardrail is impacted. A significant amount of guardrail in Kentucky varies from that recommended height. Most occurrences are related to reduced guardrail height as a result of resurfacing, fill settlement, outdated standards, or improper installation. The issue of maintaining guardrails at the proper height is briefly addressed in Appendix A of this report.

Benefits associated with removal of roadside hazards have been well documented and most highway agencies have made significant accomplishments in that area. However, some roadside hazards cannot be eliminated or the cost of removal is prohibitive. An alternative to removal of hazards is to shield those hazards so that the probability of a vehicle impacting them is reduced. Longitudinal barriers such as guardrail, median barriers, and bridge rails are used to shield vehicles from hazards. Installation of barriers is usually based on the relative hazard of the barrier versus the unshielded hazard. The AASHTO "Barrier Guide" (1) has been used by many states to assist in the determination of guardrail need and type. Generally, roadside barriers such as guardrail are used to shield vehicles from embankments or roadside obstacles. Warrants presented in the AASHTO publication are useful; however, considerable judgment is required to apply the generalized cases to specific problems in Kentucky. It appears that benefits could be derived from development of standards and guidelines for the installation of guardrail with special consideration given to traffic volumes, geometrics, and terrain representative of Kentucky.

Priority ranking of safety features for roadways has been accomplished when sufficient information was available to document costs and benefits. The cost-effective selection procedure for guardrail presented in the AASHTO "Barrier Guide" (1) is a method to be considered; however, input data necessary for the procedure may limit its application. With the goal of inventorying and ranking locations in need of guardrail or other barriers on all state-maintained roads, there is a need for a simplified procedure.

## STANDARDS FOR INSTALLATION AND REPAIR OF GUARDRAIL

### SURVEY OF GUARDRAIL STANDARDS AND REVIEW OF LITERATURE

As part of a previous research study, a survey of guardrail end treatment usage was conducted and the results were documented (2). In addition to end treatment usage, most states also provided information related to their guidelines and standards for installation of guardrail. Specific attention was given to the subject of guardrail standards being used by states that were less restrictive than those given in the AASHTO "Barrier Guide" (1). Categories of information included in the summary and of special interest for this study were clear zone widths, embankment heights and slopes, and ranges of volumes and speeds for which guardrails are warranted. Another category of information desired was related to guardrail details such as type of end treatment, type of posts, post spacings, and use of blockouts.

Some states provided more detailed information than others and some included reports or manuals that documented their policies and procedures. Even though the survey was performed in 1983, and was therefore dated, it did serve the purpose of providing sufficient information about states that should be investigated further. Responses were obtained from all states and a summary of their responses is presented in Appendix B.

It was found that most states suggesting reduced standards considered them only for low volume, low speed roads. The Georgia Department of Transportation developed guidelines for guardrail need and location that varied by traffic volume and speed (3). Figures were prepared for different volume ranges to show the warrants for guardrail at embankments based on fill height and slope. This was apparently done in an effort to provide more information than was previously given in the 1977 AASHTO "Barrier Guide" (1) for guardrail warrants. From the figure shown in the "Barrier Guide" (Figure 1), it can be seen that barriers were warranted for embankment heights exceeding 10 feet and slopes 3:1 or greater. Generally, the figure shown in the "Barrier Guide" (1) was for higher volume, higher speed roads; and therefore a need existed to develop warrants for a lower class of roads. Georgia developed a series of figures representing five volume ranges such that varying classes of roads could be evaluated for guardrail installations with some consideration being given to the exposure probability based on AADT.

In addition to embankment criteria, Georgia also prepared clear zone width criteria in the form of a nomograph relating slope, speed, and volume to clear zone width. Guidelines and warrants developed by Georgia were cited in the AASHTO "Roadside Design Guide" (4) as examples that should be followed by other states in the development of their own warrants.

Additional development of guardrail installation criteria was done by the Pennsylvania Department of Transportation (5), and they used as a guide the work previously accomplished by Georgia (3). Pennsylvania's task force concluded that the 30-foot clear zone should be retained as the desirable maximum clear recovery area, with site-specific reductions based on varying conditions of slope, AADT, and speed. The result was a table of clear zone width, cross tabulated with embankment slope, operating speed and AADT. Pennsylvania also analyzed Georgia's embankment slope and fill-height criteria to evaluate the applicability to their conditions. A table for reduced criteria was developed with slope categories ranging from 1-1/2:1 to 2-1/2:1 and four volume categories. It was noted that the fill-height criteria was highly dependent upon severity index and reference was made to the work done by Glennon and Tamburri (6) on the development of severity indices based on California accident data.

Another approach to defining the required clear zone width was developed by the Indiana Department of Highways (7). The traversable area adjacent to the pavement edge was defined by a set of curves adapted from the 1977 AASHTO "Barrier Guide" (1). The curves are very similar to those developed by Georgia (3), except there was only one scale of clear zone widths, unaffected by AADT. The curves were for tangent sections and various side slopes; developed assuming essentially an infinite length of side slope and 12-foot shoulders. For roadway sections with horizontal curves, adjustment factors were developed for curvature and AADT. Clear zone requirements were developed for cut section and fill section slopes ranging from 3:1 to 10:1. It was noted that the clear zone requirement for fill sections with 3:1 slopes and a design speed of 60 mph was 100 feet. This requirement would have applied to roads having AADT's of 6,000 or more; with less clear zone needed for lower volumes.

Clear zone guidelines have also been adopted for use on RRR projects in Kentucky (8). These guidelines vary by type of road and AADT, with advice given that the criteria are not absolute and engineering judgment should be used. For example, on projects in rural areas that have average running speeds greater than 40 mph, headwalls and parapets are recommended to be relocated if they are within 4 feet of the usable shoulder. Utility poles, trees and other similar hazards are recommended to be removed or relocated if they are within 12 feet of the edge of the traffic lane. For speeds 40 mph or less, the recommended clear zone for headwalls and parapets is 2 feet; however, if they are not relocated and are within 6 feet of the traffic lane, an object marker is required. The required clear zone for utility poles, trees and other similar objects is reduced to 10 feet for speeds 40 mph or less. Even less strict requirements are recommended for rural collector roads with speeds of 40 mph or less and AADT's less than 750.

## AASHTO ROADSIDE DESIGN GUIDE

The AASHTO "Roadside Design Guide" (4) was developed as an update of the 1977 AASHTO "Barrier Guide" (1). The "Roadside Design Guide" (4) was intended to be an updated, consolidated, and expanded source of information containing existing publications and policy statements which pertain to safer roadside design. The publication contains information and guidance on many aspects of safer roadside design for public streets and highways. Information has been extracted from several other AASHTO publications in order to compile in one source the most up-to-date guidelines relating to roadside safety. As most other AASHTO publications, the "Roadside Design Guide" (4) is not intended to be a standard or policy document, but it is intended as a guide to practices which may be adopted by highway agencies responsible for roadside design, construction, and maintenance.

Information contained in the "Roadside Design Guide" (4) that was of particular usefulness to this study was contained in the sections dealing with clear zones, embankments, and the cost-effectiveness analysis. The cost-effectiveness procedure in the 1977 "Barrier Guide" (1) allowed a designer to examine alternate safety treatments at specific locations to determine which one was more appropriate. In addition, the procedure was used by several highway agencies to analyze site-specific alternatives and to develop warrants in chart and tabular form using local data. Revisions to the cost-effectiveness procedure and adaption to a microcomputer format has made the new procedure included in the "Roadside Design Guide" (4) more attractive to the user in terms of speed and flexibility. In general, the cost-effectiveness procedure permits a designer to predict total costs of various alternatives under consideration. Total costs include initial construction costs, anticipated repair and maintenance costs, salvage value of the improvement, and user costs. User costs were based on the expected number and severity of accidents associated with each alternative. The number of accidents is directly related to the number of predicted encroachments and the probability of the encroachments resulting in an impact with a roadside hazard. Modifications to the procedure that are incorporated into the microcomputer program include; 1) an encroachment rate model, 2) a model relating lateral extent of encroachment and accident severity to design speed, and 3) a traffic growth-rate model.

The clear roadside concept was promoted in the second edition of the AASHTO "Yellow Book" (9). It was recommended that an unencumbered roadside recovery area as wide as practical would be desirable. As a result, most highway agencies began to attempt to provide a traversable and unobstructed roadside area of 30 feet or more from the edge of the driving lane. It was noted in the "Yellow Book" that previous studies had shown 80 percent of the vehicles leaving the roadway out of control were able to recover within a width of 30 feet. The 1977 AASHTO "Barrier Guide" (1) modified the 30-foot clear zone concept by including variable clear zone distances based on speeds and roadside geometry (Figure 2). This same set of curves for clear zone distances was modified further in the "Roadside Design Guide" (4) to include traffic volume along with speed and roadside geometry (Figure 3). It was noted that curves shown in Figure 3 were based on empirical data which were extrapolated to provide information on a wide range of conditions. It was also cautioned that site-specific conditions must be kept in mind when attempting to use the curves. Adjustment factors were developed for horizontal curvature with increasing clear zone requirements for increasing curvature.

Embankments on fill slopes are generally categorized as recoverable, non-recoverable, traversable, or critical. Recoverable slopes are embankment slopes 4:1 or flatter. Vehicles on recoverable slopes can usually be stopped or steered back to the roadway. A non-recoverable slope is defined as one which is traversable, but such that a vehicle cannot be stopped or returned to the roadway easily. Embankments between 3:1 and 4:1 generally fall into this category. Slopes steeper than 3:1 are critical and are usually defined as a slope on which a vehicle is likely to overturn. As shown in Figure 1, embankment height and slope are the basic factors considered in determining barrier need. Again referring to Figure 1, it can be seen that embankments with slope and height combinations on or below the curve do not warrant shielding unless there are obstacles within the clear zone that present a serious hazard. It was noted that some states had developed modified warrants to account for the decreased probability of encroachments on lower volume roads (Figures 4 and 5).

KENTUCKY GUARDRAIL POLICY

Kentucky's Department of Highways' Maintenance Guidance Manual (10) provides guidance for new guardrail installations and upgrading existing guardrail installations. It is noted that all projects for guardrail installation and upgrading shall meet the warrants of Part I-III-A of the 1977 "AASHTO Barrier Guide" (1). Each highway district is required to maintain a current inventory of all substandard and obsolete guardrail and all unshielded locations which are known to meet the warrants of Part I-III-A of the "Barrier Guide" (1). In addition, it is required that a cost-effectiveness ranking be defined for each location based on a statewide inventory. An additional requirement is that the Department of Highways' Division of Maintenance prepare and administer an annual Guardrail Improvement Program. Funds budgeted to this program are to be allocated to those locations having the highest ranking factor and those that can be constructed without major reconstruction of the roadway. Alternatives to guardrail, such as hazard removal or relocation, flattening slopes, and pipe extensions are to be considered and may be included in the program.

The issue of when to upgrade guardrail and when to repair or maintain with equivalent materials is a continuing problem. It is desirable that guidelines exist for details to be included in standards for repair and maintenance of guardrail on existing roadways that have not been designed and built to current standards. Current general policy is that obsolete or substandard guardrail may be repaired or maintained with equivalent materials in stock or with available guardrail elements.

## RECOMMENDED GUARDRAIL STANDARDS AND GUIDELINES

GUARDRAIL NEED GUIDELINES

The "Roadside Design Guide" (4) contains figures and tables giving warrants for guardrail based on embankments and roadside obstacles. When considering the need for guardrail relative to embankments, the embankment height and side slope are the factors used to make the decision. The relative severity of encroachments on the embankment must be compared to impact with the guardrail. A figure using fill section height and slope was included in both the "Barrier Guide" (1) and "Roadside Design Guide" (4) (Figure 1). Modified warrant charts were included in the "Roadside Design Guide" (4) (Figures 4 and 5) that consider the decreased probability of encroachments on lower volume roads. The need for guardrail relative to roadside obstacles considers the necessary clear zone for the given roadway and the relative severity of hitting the obstacle versus the guardrail. Table 1 and Figure 3 which were taken from the "Roadside Design Guide" (4), give the necessary clear zone as a function of design speed, traffic volume, and fill or cut slope. While warrants were presented for the need for guardrail based on embankment and roadside obstacle criteria in the "Roadside Design Guide" (4), the recommendation was made that highway agencies develop specific guidelines for their agency based upon their cost-effectiveness evaluations. A cost-effectiveness selection procedure was given in Appendix A of the "Roadside Design Guide" (4). This procedure was used to develop guidelines for the need of guardrail based on Kentucky data. A computer program (ROADSIDE) was obtained to conduct the cost-effectiveness analysis.

Certain parameters had to be used in the computer program. These parameters are given as part of the computer program and values are specified unless changed. The parameters used in the analysis are shown in Figure 6. The accident cost figures and encroachment model were changed from that given as part of the computer program. The accident cost figures were based on the recommendations given in FHWA Technical Advisory T7570.1 (11). The encroachment model was obtained from TRB Special Report 214 (12). This model is the exponential encroachment model given in Appendix F of Special Report 214 (12). The decision to use this encroachment model was made after analyzing the output from the program using alternate encroachment models. The model presented in Special Report 214 (12) considered curvature and grade while the model presented in ROADSIDE (4) required the curvature and grade to be input each time. For the type of analysis performed in this study, it was felt that the model in Special Report 214 (12) would result in a more useful methodology. Also, comparison of results of analyses using both models supported the use of the Special Report 214 (12) exponential encroachment model.

Two separate types of analyses were conducted. They were related to clear zone and embankment criteria. The computer program required various types of input and the output was the total cost (including the accident cost, installation cost, repair cost, maintenance cost, and salvage value). The total cost was then compared for both having and not having a guardrail using the appropriate set of assumptions. These were the only two alternatives considered. When the total cost with a guardrail present became less than with no guardrail, it was assumed that a guardrail was warranted.

A printout of the input and output data from a sample computer run is given in Figure 7. Some of the required input was constant for all the analyses. The traffic growth rate was assumed to be 2.5 percent. A two-lane, undivided highway was used with a lane width of 11 feet. The curvature remained at zero degrees while the grade was held at zero percent. This could be done since the encroachment model considered the effect of curvature and grade as part of the model. A project life of 20 years was used along with a discount rate of 7 percent. The cost of repair of guardrail after an accident was estimated to be $500 with no maintenance cost or salvage value.

The remaining input values were varied with the objective of finding the point at which the total cost with the guardrail was less than the cost without a guardrail. This would be the point at which a guardrail would be warranted. The variables which were varied included the traffic volume, design speed, lateral placement, longitudinal length, width of obstacle, severity index, and cost of installation.

In the clear zone analysis, the total costs of impacting a guardrail or fixed object at an isolated point with a longitudinal length of one foot and a width of one foot were compared. The lateral offset of the fixed object was varied with a two-foot offset of the fixed object behind the guardrail and a maximum lateral offset of 10 feet for the guardrail. Severity indices were calculated using Kentucky accident data. The severity of accidents involving a collision with a guardrail or a tree as the first event were compared as a function of speed limit. The severity indices used for guardrail were 2.2 for 40 mph, 2.5 for 50 mph, and 2.8 for 60 mph. The severity indices used for fixed objects were 3.1 for 40 mph, 3.4 for 50 mph, and 3.7 for 60 mph. The program limited the speeds to either 40, 50, or 60 mph. An installation cost of $2,000 was used for the guardrail.

Numerous series of computer runs were conducted with the traffic volume and speed held constant and the lateral offset varied. For a specific volume and speed, two sets of computer runs were made. One used the data assuming no guardrail while the second assumed the appropriate data for guardrail. When the total cost at the lateral offset of the guardrail became less than that for a corresponding offset for the fixed object, the guardrail was determined to be warranted. The results of these analyses are given in Table 2. The traffic volume categories varied from 250 to "over 5,000" with speed categories of 40, 50, and 60 mph. For the 50-mph speed category, the minimum clear zone distance needed without the installation of guardrail varied from 3 feet for an ADT of 250 to 20 feet for an ADT of over 5,000.

A similar type of analysis was used in the embankment analysis. A limiting factor in this analysis was the lack of data relative to the severity of accidents as a function of embankment height and slope. The only accident data noted which yielded accident severity versus embankment height and slope were single vehicle embankment accidents in California in 1963 (6). It should be noted that the data base representing California embankment accidents in 1963 consisted of a greater proportion of larger cars than are currently in the vehicle fleet. Larger cars are less likely to overturn than smaller cars because they are more stable due to their wider track width. Severity indices compatible with indices for accidents involving guardrail in Kentucky were calculated using these data and a severity index formula used in Kentucky (13) (Table 3). It was not possible to calculate the severity index as a function of speed. The overall severity index of all accidents involving guardrail in Kentucky was calculated as 2.67. This severity index was compared to those calculated using the California data. It can be seen that the severity of hitting a guardrail (severity index of 2.67) was greater than that for driving over an embankment when the slope was 3:1 or flatter. Therefore, no guardrail could be warranted for a slope of 3:1 or flatter. It should be noted that the severity of an accident involving an embankment relates to the vehicle overturning and/or striking fixed object hazards either on the slope or at its base.

Therefore, these severity indices must be used with caution for slopes that are non-traversable or include fixed objects.

A speed of 50 mph was used in the embankment analysis. The severity indices were not classified by speed so one representative speed had to be selected. It was felt that the 50 mph speed would be most representative of the roads for which this analysis would be used. For the guardrail installation, a lateral placement of 5 feet was assumed with a longitudinal length of 200 feet and a width of one foot. When the embankment was considered, a lateral placement of 7 feet was assumed with a longitudinal length of 200 feet and a width of the embankment height times the slope (for example, the width would be 20 feet for an embankment height of 10 feet and a slope of 2:1). For a given traffic volume, the total cost of the guardrail was compared to various embankment heights. When the cost associated with the embankment exceeded that for the guardrail, a guardrail was warranted. The results of this analysis are presented in Table 4. For a slope of 2:1, the embankment height at which guardrail was warranted varied from 40 feet for an ADT of 250 to 15 feet for an ADT of over 5,000. When the slope became steeper than 2:1, a guardrail was basically warranted in all cases when the embankment height was above a minimum level. Using Figure 1 ("Roadside Design Guide" Figure 5.1) (4) as a reference, this minimum embankment height would be about 5 feet.

## GUARDRAIL HARDWARE FOR LOW SERVICE LEVEL ROADS

Reduced guardrail standards and related hardware for lower volume roads were the subjects of research reported by Kimball and Hancock as part of a NCHRP study titled "Develop Performance Standards and Hardware for Low Service Level Guardrail System" (14). The overall objectives of this study were to 1) examine the need for guardrail on low service level roads, 2) develop performance standards for guardrail, transitions, and terminals to meet these needs, and 3) design, test, and develop low-cost guardrail systems based on these performance standards. Primary results were preliminary performance standards and warranting criteria for low service level guardrail systems. Performance standards were reduced from those recommended in NCHRP Report 230 (15); which included a 4,500-pound vehicle tested at 60 mph and a 25-degree approach angle. For low service level roads, the test conditions used were a 3,400-pound vehicle impacting the guardrail system at 50 mph and a 20-degree impact angle. Warranting criteria developed as part of the study were apparently not implementable due to small sample sizes of supporting data. The warranting procedure was compiled into an interactive computer program. Guardrail systems selected as most appropriate for use on low service-level roads were 1) 12-gauge W-beam guardrail with 4 pounds/foot steel u-channel posts, 2) 12-gauge W-beam guardrail with 5-1/2-inch diameter wood posts, 3) 3/4-inch cable guardrail with 4 pounds/foot steel u-channel posts, and 4) 3/4-inch cable guardrail with 5-1/2-inch diameter wood posts. Even though testing of terminals was not part of the study, it was recommended that the Texas Twist (weakened turned-down similar to Kentucky's Type 7 end treatment) was the least expensive option and was considered to be adequate for lower performance standards. Optional posts for both systems (W-beam guardrail and cable) were the S3x5.7 steel posts. Post spacings were 16 feet for the cable systems and 12 feet, 6 inches for the W-beam systems. Details of each of the guardrail systems are presented in Appendix C.

The guardrail systems recommended (14) for use on low service level roads are lower cost, lower performance versions of the operational roadside barriers presented in the 1977 "AASHTO Barrier Guide" (1). They provide for the substitution of u-channel 4 pounds/foot metal posts and 5-1/2-inch diameter wood posts for the S3x5.7 steel posts. In general, these guardrails deflect more than the operational roadside barriers. Increased post spacings reduce their cost, but also reduce their strength. Similar post systems are shown in the "Roadside Design Guide" (4) where they are identified as "Selected Roadside Barrier Design Details".

From the survey of guardrail usage in other states (2), provisions for lower guardrail hardware standards were examined. Generally, there were few exceptions to the standards and guidelines presented in the "AASHTO Barrier Guide" (1). However, it was noted that Georgia offered standards for design of guardrail by type of highway but there were few differences. Minnesota had a provision for post spacing of 12 feet, 6 inches where the speed was under 50 mph. Pennsylvania's guidelines included the use of a weak post system without blockouts. Schultz (5) also reported that a strong-post system using 12 foot, 6 inch spacing was considered by Pennsylvania, but was rejected because of the potential tort liability compared to the potential savings by reducing the number of posts. Virginia's response indicated that both strong post (with blockout) and weak post systems without blockouts were used. West Virginia reported that, based on design year AADT and design speed, guardrail designs would be one of the following: 1) 6 foot, 3 inch spacing with blockouts, 2) 12 foot, 6 inch spacing with blockouts; or 3) 12 foot, 6 inch spacing without blockouts. The turned-down end treatment was usually mentioned when lower guardrail standards were considered.

Generally, there were few examples of states that had formal guidelines for lower guardrail standards for low service level roads. As noted previously, the 1977 "AASHTO Barrier Guide" (1) and the new "Roadside Design Guide" (4) did offer weak-post systems without blockouts as operational systems (Appendix C). A concern related to use of the W-beam, weak-post guardrail system with 12 foot, 6 inch post spacings may be the maximum dynamic deflection, which is approximately 7 feet in a 59 mph test. An alternative, when maximum deflection may present a problem, is the Thrie beam, weak-post system which has maximum dynamic deflection of approximately 4 feet. Where Thrie beam guardrail is not used extensively, the initial cost and readily accessible replacement components may be a problem. Another alternative, which was tested and reported as part of NCHRP Report 115, is the W-beam, weak-post system with 6 foot, 3 inch post spacings (16). Results from full-scale crash tests indicated that maximum dynamic deflection was 5.8 feet as compared to 7.3 feet for the same system with 12 foot, 6 inch post spacings. These systems could be considered on low volume roads where the W-beam, blocked-out guardrail system may be impractical due to geometric, terrain, or cost constraints. However, with a priority ranking procedure based on accident history, operational characteristics, and roadway geometrics; it is unlikely that low service level roads would be identified and ranked highest as locations in need of guardrail.

## DEVELOPMENT OF A PROCEDURE TO IDENTIFY AND PRIORITIZE LOCATIONS IN NEED OF GUARDRAIL

### DEVELOP CRITICAL NUMBERS AND RATES OF RUN-OFF-ROAD ACCIDENTS

A procedure has been in place for several years to develop average and critical accident rates for use by the Kentucky Department of Highways in the identification of high-accident locations (17). These locations have routinely been inspected and accident data have been analyzed to offer recommendations for improvements, when appropriate. Another study resulted in the development of accident reduction factors for use in the cost-optimization procedure to rank proposed safety improvements (18).

The general procedure to develop critical accident numbers and rates relies on the historical accident file and a volume file. Accident data are available from the Kentucky Accident Records System (KARS). Volume data used for the calculation of accident rates were obtained from the Statewide Mileage File.

As previously noted, the general procedure to develop accident rates has been documented (17, 19). An annual report is now produced to calculate average and critical rates as a means of analyzing statewide accident statistics (20). It was necessary to determine numbers of accidents and to develop average rates and critical rates as input for the high-accident identification program. The following formulas were used to calculate critical accident rates and numbers (17, 19):

$$A_c = A_a + K(\mathrm{sqrt}(A_a/M)) + 1/(2M)$$

in which

$A_c$ = critical accident rate,
$A_a$ = average accident rate,
sqrt = square root,
K = constant related to level of statistical significance selected (a probability of 0.995 was used wherein K = 2.576), and
M = exposure (for sections, M was in terms of 100 million vehicle-miles (100 MVM); for spots, M was in terms of million vehicles.

To determine the critical number of accidents, the following formula was used:

$$N_c = N_a + K(\mathrm{sqrt}(N_a)) + 0.5$$

in which

$N_c$ = critical number of accidents and
$N_a$ = average number of accidents.

To permit the use of this procedure to develop average and critical numbers and rates of accidents for use with the guardrail location selection program, it was necessary to modify the procedure to identify only those accidents associated with vehicles running off the road. Directional analysis codes assigned after interpretation of the details provided on the police accident report and included in the accident file were determined to be the best source of information to identify run-off-road accidents. It was assumed that guardrail installation would be of benefit only in accidents where vehicles ran off the road. Analysis of the directional analysis codes revealed that three types of accidents made up a very high percentage (99 percent) of the total. Those three types of accidents were: 1) single-vehicle collision with a fixed-object at an intersection; 2) single-vehicle collision with a fixed-object not at an intersection; and 3) single-vehicle, run-off-road accident, not at an intersection. The magnitude of the frequency of these types of accidents, along with others identified as run-off-road, are shown in Table 5 for the period of 1983 through 1987.

As shown in Table 6, approximately two-thirds of all run-off-road accidents involve collisions with fixed objects. Presented in Table 6 is a summary of fixed-object accidents and their overall severity based on a calculated severity index (13). It can be seen by the magnitude of the severity index that the most severe fixed-object accidents are those involving trees (3.52), culvert/headwalls (3.38), earth embankments/rock cuts/ditches (3.14), and bridges (2.95). The most frequently occurring fixed-object accidents are collisions with earth embankment/rock cut/ditch, trees, utility poles, and fences. The least severe accidents are those involving buildings/walls (1.56) and fire hydrants (1.70). The severity index for guardrail impacts was 2.67; which was in the mid-range of severity indices.

After identification of those accidents which could be affected by the installation of guardrail, average and critical numbers and rates of run-off-road accidents were summarized for one-mile sections. For the time period of 1983 through 1987, the average and critical numbers are shown in Table 7 for various highway types. Accident rates by highway types for rural and urban areas are presented as Tables 8 and 9, respectively. These tables also show total mileage and annual average daily traffic (AADT) for each highway type. Using the previously referenced equation, critical accident rates were calculated for each type of rural and urban highway; and cross-tabulated by volume category and section length (Appendix D). Tables D-1 through D-7 are critical run-off-road accident rates for rural sections and Tables D-8 through D-13 are critical rates for urban sections. Also presented are critical run-off-road accident rates for spots (defined as highway sections 0.3 mile in length) on rural and urban highways (Tables E-1 through E-4 in Appendix E).

## PREPARE LIST OF LOCATIONS HAVING CRITICAL RATES OF RUN-OFF-ROAD ACCIDENTS

Through the cooperation and assistance of the Department of Highways' and the Department of Information Systems' personnel, the existing computer program to identify high-accident locations was modified to identify run-off-road accident locations. Output from this computer program was a listing of accident locations by decreasing critical rate factor in order of county, route, and mileposts. For this analysis, the critical rate factor was defined as the average accident rate for a section divided by the critical rate for that same section. Other information presented in the printout included number of accidents, number of lanes, highway class, rural/urban designation, and AADT. The listing represented all highway sections of one-mile length with five or more accidents in a five-year period. An example printout is presented in Figure 8. It was assumed from the beginning that sections one mile in length were the most appropriate for analysis to determine the need for guardrail; however, 0.3-mile sections with three or more accidents in a five-year period were also analyzed and determined to have advantages as alternate means of identifying locations in need of guardrail. A similar computer summary was prepared for 0.3-mile sections listing accident locations by decreasing critical rate factor in order of county, route, and mileposts. Another form of output from the run-off-road accident identification procedure was a listing of all locations with critical rate factors greater than 1.0. A critical rate factor greater than 1.0 means that the accident rate for a section of highway exceeds the critical rate for that class or type of highway statewide. An example of this printout is shown in Figure 9 and it includes a detailed description of each accident categorized as run-off-road. Included for each accident are the following; milepost location, date of accident, directional analysis, description of accident type, light condition, road surface condition, collision type, and number injured and/or killed.

These listings represent the first step of a method for identification of locations in need of guardrail. With the use of previously discussed computer printouts of locations with critical rates of run-off-road accidents, a listing by county can be prepared for selecting highway sections which should be subjected to the field survey. This procedure would eliminate the need to survey all highway sections; thereby concentrating efforts on sections previously identified as having accident rates exceeding the critical level. Locations with critical rates greater than 1.0 have high accident rates; however, these locations do not necessarily need guardrail because guardrail may already exist or there may be other improvement alternatives.

A total of 1,069 one-mile and 2,845 0.3-mile sections were identified throughout the state. By highway districts, the highest number of 0.3-mile sections were in District 7 (529) with the lowest number in District 10 (62). Jefferson County had the highest number of 0.3-mile sections identified (178) with five counties having none identified.

## DEVELOP A HAZARD-INDEX POINT SYSTEM

Prior to conducting a field survey, there was a need to develop a system for relating the operational and geometric characteristics of highway sections with their accident history to determine which sections exhibited the greatest need for guardrail. In addition to accident statistics, there are several characteristics which can be associated with the potential for accidents. The following characteristics were selected to represent a hazard-index rating of highway sections.

| CHARACTERISTICS | RATING POINTS POSSIBLE |
|---|---|
| 1) Number of run-off-road accidents | 15 |
| 2) Run-off-road accident rate | 15 |
| 3) Traffic volume | 10 |
| 4) Speed limit or prevailing speed | 10 |
| 5) Lane and shoulder width | 10 |
| 6) Roadside recovery distance | 10 |
| 7) Embankment slope | 10 |
| 8) Embankment height | 10 |
| 9) Culvert Presence | 5 |
| 10) Subjective Roadside Hazard rating | 5 |

An attempt was made to include characteristics representative of accidents and accident potential, operations, and cross section. Point-system weightings of each characteristic were determined by subjective evaluation (the rating form is presented as Figure 10). It can be seen that the combination of number of accidents and accident rate made up 30 of a possible 100 points. Traffic volume and speed limit, considered to be operational characteristics, totaled 20 of the possible 100 points. Cross-section characteristics made up an additional 40 points. Because of their frequency of occurrence and the hazard associated with culvert headwalls or openings near the roadway, a special category was created to represent this condition. For a culvert present within five feet of the road, 5 points were assigned. Also included was a general category representing a subjective roadside hazard rating with 5 points possible. This rating was based on a visual observation that was compared to photographic documentation of roadway sections depicting various degrees of roadside hazard.

## CONDUCT FIELD SURVEY

Another step in the overall process of identifying locations in need of guardrail is a field survey of locations having critical rate factors of 1.00 or greater. Specific cross-section information that will require a field survey includes the following: 1) lane and shoulder width, 2) roadside recovery distance, 3) embankment slope, 4) embankment height, 5) presence of a culvert, and 6) subjective roadside hazard rating. Additional field data collection may be required to obtain prevailing speed if it is less than the speed limit.

In order to implement the field survey process, a form was developed for use by Kentucky Department of Highways' personnel to document roadway cross-section and other conditions determined to be useful (Figure 11). This form includes space for all variables that will require rating points to be assigned, in addition to general location information and accident statistics.

It is recommended that additional information be documented for each highway section to be surveyed. Included will be the following general information: date, county, district, route number, range of milepoints, type of area, terrain, AADT, and number of lanes. The result will be a combination of field data collection and other data collection; primarily from files maintained by the Department of Highways. Only 10 variables or characteristics will be assigned hazard-index rating points. Other characteristics for which data are not to be collected will not be assigned rating points but will be available to provide general information to the decision-maker.

Tests of the survey form shown in Figure 11 were conducted to determine if it was reasonable and understandable for use by field personnel to document operational and cross-section information. It was determined that a listing of accident locations by county having critical rate factors shown would provide sufficient information to select those locations to be surveyed. An example of the accident listing by county is shown in Figure 12. This listing is arranged by increasing route number within a county and milepoints are given to permit location of a specific section on a route. In addition, critical rate factors are tabulated for use in selecting factors greater than 1.0 or some other desirable minimum level. With the information as shown in Figure 12, a county map and route milepoint log can be used to identify locations on the map so that the field survey process is made more efficient. The remaining information necessary to prepare for and complete the field survey process were detailed listings of individual accidents at 0.3-mile and 1.0-mile sections as was previously shown in Figure 9. The resulting package of information determined to be necessary to efficiently conduct the field survey was the following: 1) a listing of accident locations by county with critical rate factors tabulated, 2) a county map, 3) a route milepoint log by county, and 4) a detailed listing of individual accidents for 0.3-mile and 1.0-mile sections.

TABULATE HAZARD-INDEX POINTS

After assignment of hazard-index points to each of the variables or characteristics (from the accident history and the field survey), the next step will be to summarize and tabulate hazard-index points for each highway section. It is recommended that lists of locations be prepared with total hazard-index points in decreasing order for all locations statewide and then for several subcategories such as district, county, and highway class (Federal-Aid or functional class). The purpose for this listing will be to identify a manageable number of locations for which cost-effectiveness analysis can be performed. The result will be a listing of locations with a combination of accident history and cross-section characteristics that could serve as the basis for collection of cost and benefit data.

DETERMINE IMPROVEMENT COSTS

As part of the field survey process, it will be necessary to evaluate each location having a critical rate factor of 1.00 or greater to determine if improvements should be recommended. Because the run-off-road accident analysis will identify locations based only on number and rate of accidents, it is likely that some locations having existing barriers or other roadside improvements will appear on the list. This will require that each location be assessed to determine if any improvement should be made. However, it is anticipated that improvement alternatives will be available at the majority of locations and the type and cost of these improvements will need to be documented.

At the beginning of this study, it was generally assumed that the primary type of improvement would be installation of guardrail. The focus on guardrail was the result of an initial request to identify locations in need of guardrail so that a prioritized listing could be prepared and made available to the Department of Highways. This listing was to be used to assist in the selection of projects to be funded for installation and enhancement of guardrail. It is obvious that several alternatives usually exist when encountering roadside hazards. Among the most frequently mentioned are removal/relocation of fixed objects and flattening side slopes. Frequently encountered roadside hazards and the cost to remove or reduce the hazard potential were tabulated by Zegeer, et al. (21). Excerpts from that work are included as Appendix F. Additional information on improvement costs are available from the Kentucky Department of Highways' unit bid prices which are tabulated for all projects awarded during each calendar year (22). An example of unit bid prices, including W-beam guardrail installation ($8.06 per linear foot), is also included in Appendix F.

## DETERMINE IMPROVEMENT BENEFITS

The benefits of improvements associated with roadside hazards are primarily due to reduced accidents. To determine the expected benefits from various types of improvements, it will be necessary to relate accident reduction factors to specific types of improvement alternatives. Previous work by Creasey and Agent (23) provides a wide range of accident reduction factors that may be directly applied to improvements recommended as part of this program. Selected accident reduction factors from Creasey's and Agent's work (21) that may be related to run-off-road accidents are tabulated in Appendix G. Included are reduction factors for the following major areas of safety improvements: 1) pavement marking, 2) construction/reconstruction, 3) safety barriers, 4) safety poles and posts, and 5) removal/relocation of roadside obstacles. Detailed accident data for each location will be available from the run-off-road accident summaries prepared as part of the analysis to determine critical rates. Previously noted was the type of information presented in Figure 9 which shows number of fatalities, number of injuries, and total number of accidents. These data can be converted to total accident benefits by associating accident severity (types of injuries and property damage) with costs for each type. Costs for each level of accident severity have been developed and recommended by the Federal Highway Administration (10). Those accident costs recommended by the Federal Highway Administration and recommended for use in determining improvement benefits areas follows: 1) Fatality - $1,500,000, 2) Injury - $11,000, and 3) Property Damage Only - $2,000. Therefore, the combination of accident reduction factors, accident severity from the historical data at a specific location, and costs for each accident severity level will result in an accident reduction benefit (cost savings) associated with each improvement alternative.

## ANALYZE COST-EFFECTIVENESS

The final step in the process of evaluating roadside safety needs is to combine cost and benefit data to determine the cost-effectiveness of alternative improvements. A simple listing of improvement alternatives in order of decreasing benefit-cost would provide information to allow selection of locations with the greatest benefit-cost ratio. However, with restricted budget amounts available, it would be appropriate to use a budget optimization procedure to select those alternatives such that maximum benefits could be derived.

Input required for the budget optimization procedure includes the following:

1) number of locations to be analyzed,
2) budget levels to be considered,
3) costs assigned to each accident severity,
4) interest rate,
5) traffic growth rate,
6) accident history,
7) alternatives for reducing accidents,
8) expected improvement life,
9) improvement cost,
10) annual maintenance cost, and
11) expected reductions in accidents due to improvements.

Documentation of a procedure for budget optimization was prepared by Crabtree and Mayes and adapted for the Highway Safety Improvement Program in Kentucky (24). Examples of input and output from this procedure are shown in Appendix H. It can be seen that budget optimization results in the selection of projects that are not necessarily in the same order as a ranking by decreasing benefit-cost ratio.

Output from the budget optimization procedure will be a listing of information for each location; consisting of the location number, the location name, the accident history, the input for each improvement alternative, and the benefit-cost ratio for each alternative. For each budget specified, a listing will be provided showing the selected alternative at each location, alternative costs and benefits, and the benefit-cost ratio.

In general, budget optimization will provide a listing of selected projects and selected alternatives for a given budget. If a certain amount of money is designated for roadside safety improvements, this procedure will allow maximum benefits to be achieved.

## SUMMARY OF RESULTS

Following is a summary of significant results related to this investigation of standards and guidelines for guardrail installations.

1. From a previous survey of guardrail standards and guidelines, it was determined that only a few states suggested use of reduced guardrail standards. Georgia, Pennsylvania, and Indiana were exceptions, with lower standards considered only for low volume, low speed roads.

2. The AASHTO "Roadside Design Guide" (4) offered general guidance related to roadside safety and suggested that states develop their own warranting criteria for clear zones and embankments based on localized cost-effectiveness.

3. Kentucky's guardrail policy requires administration of an annual Guardrail Improvement Program, including a cost-effectiveness ranking for each location based on a statewide inventory.

4. A computer program (ROADSIDE) from the "Roadside Design Guide" (4) was modified and used to develop warranting guidelines for clear zones and embankments based on accident severities and costs representative of Kentucky conditions.

5. A review of literature was conducted to determine the types of guardrail hardware recommended for low service level roads. In general, there were few exceptions to the "Barrier Guide" (1) and the "Roadside Design Guide" (4). Several operational barrier systems are presented in the "Roadside Design Guide" that may be considered for low service level roads when the W-beam, blocked-out guardrail is not practical.

6. A procedure was developed to identify and prioritize locations in need of guardrail based on the following steps:
    a) Development of critical numbers and rates of run-off-road accidents,
    b) Preparation of a list of locations with critical rates of run-off-road accidents,
    c) Development of a hazard-index point system,
    d) Conducting a field survey,
    e) Tabulation of hazard-index points,
    f) Determination of improvement costs,
    g) Determination of improvement benefits, and
    h) Analysis of cost-effectiveness.

## IMPLEMENTATION

A procedure was developed to identify and prioritize highway sections in need of guardrail. This procedure will permit adoption of a systematic process of identifying locations with the greatest need for guardrail. Based on an initial selection of locations with critical numbers and rates of run-off-road accidents, a field survey will be required to catalog operational and cross-section characteristics for input into a hazard-index point system. It is recommended that locations be categorized in decreasing order of hazard-index points statewide and for subcategories such as district, county, or highway class. When only guardrail is considered as an improvement alternative, the need for guardrail can be determined based on a comparison of cross-section characteristics with criteria presented in Table 2 for clear zones and Table 4 for embankments. These criteria or warranting guidelines were developed using the computer program (ROADSIDE) from the "Roadside Design Guide" (4) based on accident severities and costs representative of Kentucky conditions. Whether only guardrail or other alternatives are considered, sufficient information will be available to determine improvement priorities based on cost-effectiveness and budget optimization.

Guardrail hardware for low service level roads were identified from a review of literature: and where the need to consider guardrail when the W-beam, blocked-out barrier is not practical; weak-post, box beam and cable systems presented in the "Roadside Design Guide" (4) should be considered.

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TABLE 1. CLEAR ZONE DISTANCES (ROADSIDE DESIGN GUIDE) (REFERENCE 4)

TABLE 3.1. **Clear Zone Distances (In feet from edge of driving lane)**

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

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

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

TABLE 2. CLEAR ZONE DISTANCES*

| TRAFFIC VOLUME (ADT) | CLEAR ZONE DISTANCE (FEET) | | |
|---|---|---|---|
| | TRAFFIC SPEED | | |
| | 40 MPH | 50 MPH | 60 MPH |
| 250 | ** | 3 | 12 |
| 500 | ** | 9 | 16 |
| 1,000 | 5 | 13 | 19 |
| 2,000 | 9 | 16 | 21 |
| 3,000 | 11 | 18 | 22 |
| 4,000 | 13 | 18 | 22 |
| 5,000 | 14 | 19 | 23 |
| Over 5,000 | 15 | 20 | 23 |

* The minimum clear zone distance needed without the installation of guardrail.

** An ADT of 700 was needed before the minimum two-foot clear zone would be required.

Note: Refer to text section titled "Guardrail Need Guidelines" in development of table.

TABLE 3. SEVERITY INDEX VERSUS EMBANKMENT HEIGHT AND SLOPE*

| EMBANKMENT HEIGHT (FT) | SLOPE | | | |
|---|---|---|---|---|
| | 3:1 | 2:1 | 1-1/2:1 | 1:1 |
| 3 | 2.47 | 2.71 | 2.96 | 3.44 |
| 8 | 2.51 | 2.75 | 2.99 | 3.47 |
| 15 | 2.56 | 2.80 | 3.04 | 3.52 |
| 25 | 2.63 | 2.87 | 3.11 | 3.59 |
| 35 | ** | 2.94 | 3.18 | 3.66 |
| 45 | ** | 3.01 | 3.25 | 3.74 |
| 60 | ** | 3.12 | 3.36 | 3.84 |

* Severity Index (SI) is: SI = (9.5(K+A) + 3.5(B+C) + PDO)/T
where K = fatal accident,
A = incapacitating injury accident,
B = non-incapacitating injury accident,
C = "possible" injury accident, and
T = total accidents.

** No data.

TABLE 4. EMBANKMENT GUIDELINES

| TRAFFIC VOLUME (ADT) | EMBANKMENT HEIGHT (FT)* SLOPE** 2:1 |
|---|---|
| 250 | 40 |
| 500 | 31 |
| 1,000 | 24 |
| 2,000 | 20 |
| 3,000 | 18 |
| 4,000 | 17 |
| 5,000 | 16 |
| Over 5,000 | 15 |

* The minimum embankment height needed without the installation of guardrail.

** Guardrail not warranted for slope of 3:1 or flatter. Guardrail would be warranted for a slope steeper than 2:1 when the embankment height was above a minimum level of about 5 feet.

Note: Refer to text section titled "Guardrail Need Guidelines" for methodology used in development of table.

TABLE 5. DIRECTIONAL ANALYSIS CODES USED TO DETERMINE RUN-OFF-ROAD ACCIDENTS

| CODE NUMBER | NUMBER OF ACCIDENTS 1983 | 1984 | 1985 | 1986 | 1987 |
|---|---|---|---|---|---|
| 13 | 1,407 | 1,276 | 1,569 | 2,075 | 1,795 |
| 40 | 12,838 | 13,818 | 12,908 | 11,899 | 12,574 |
| 43 | 6,068 | 7,138 | 6,957 | 6,524 | 7,311 |
| 51 | 24 | 19 | 15 | 37 | 17 |
| 52 | 1 | 0 | 3 | 4 | 0 |
| 53 | 228 | 66 | 65 | 73 | 41 |
| 54 | 175 | 66 | 82 | 45 | 46 |
| 55 | 8 | 11 | 3 | 5 | 5 |
| 60 | 30 | 9 | 5 | 0 | 5 |
| 65 | 35 | 2 | 5 | 2 | 2 |
| 66 | 42 | 21 | 18 | 52 | 16 |
| 67 | 21 | 14 | 19 | 18 | 8 |

Code No. 13 - Int - collision wtih a fixed object - single vehicle
40 - Non-int - collision with fixed object - single vehicle
43 - Non-int - ran off roadway - single vehicle
51 - Non-int bridge - collision with approach guardrail
52 - Non-int bridge - gap between bridges
53 - Non-int bridge - collision with bridge abutment
54 - Non-int bridge - collision with bridge rail or curb
55 - Non-int bridge - went through or over bridge rail
60 - Non-int bridge - ran off road after losing control on bridge
65 - Non-int ramp - collision with fixed object in gore - single vehicle
66 - Non-int ramp - collision with fixed boject not in gore - single vehicle
67 - Non-int ramp - ramp vehicle ran off roadway - single vehicle

TABLE 6. SEVERITY OF FIXED OBJECT ACCIDENTS (1984-1986)

| FIXED OBJECT | NUMBER OF ACCIDENTS | | | | PERCENTAGE | | SEVERITY INDEX* | COST ($)/ ACCIDENT** |
|---|---|---|---|---|---|---|---|---|
| | FATAL | INJURY | PDO | TOTAL | FATAL | INJURY | | |
| Guardrail | 75 | 1889 | 2096 | 5060 | 1.48 | 37.3 | 2.67 | 32,260 |
| Bridge | 30 | 611 | 897 | 1538 | 1.95 | 39.7 | 2.95 | 40,471 |
| Tree | 215 | 4057 | 3522 | 7794 | 2.76 | 52.1 | 3.52 | 55,538 |
| Utility Pole | 54 | 3164 | 4578 | 7796 | 0.69 | 40.6 | 2.68 | 19,219 |
| Sign | 17 | 562 | 2061 | 2640 | 0.64 | 21.3 | 1.91 | 16,269 |
| Culvert/Headwall | 50 | 1277 | 1186 | 2513 | 1.99 | 50.8 | 3.38 | 42,354 |
| Curbing | 13 | 380 | 1042 | 1435 | 0.91 | 26.5 | 2.16 | 21,286 |
| Earth Embankment/ Rock Cut/Ditch | 209 | 8191 | 8205 | 16605 | 1.26 | 49.3 | 3.14 | 29,786 |
| Building/Wall | 7 | 479 | 2859 | 3345 | 0.21 | 14.3 | 1.56 | 8,126 |
| Crash Cushion | 3 | 56 | 105 | 164 | 1.83 | 34.1 | 2.56 | 37,799 |
| Fence | 43 | 1497 | 4950 | 6490 | 0.66 | 23.1 | 1.96 | 16,781 |
| Median Barrier | 13 | 581 | 979 | 1573 | 0.83 | 36.9 | 2.59 | 21,088 |
| Fire Hydrant | 2 | 112 | 489 | 603 | 0.33 | 18.6 | 1.70 | 10,672 |

* Severity Index (SI) = (9.5(F + A) + 3.5(B + C) + PDO)/Total Accidents

** Based on FHWA accident cost estimates of $1,700,000 for a fatal accident, $14,000 for an injury accident, and $3,000 for a property-damage-only accident.

TABLE 7. STATEWIDE AVERAGE AND CRITICAL NUMBERS OF R-O-R ACCIDENTS FOR 0.3-MILE AND ONE-MILE SECTIONS BY HIGHWAY TYPE CLASSIFICATION (1983-1987)*

| RURAL OR URBAN | HIGHWAY TYPE | ACCIDENTS PER 0.3-MILE SECTION | | ACCIDENTS PER ONE-MILE SECTION | |
|---|---|---|---|---|---|
| | | AVERAGE | CRITICAL NUMBER | AVERAGE | CRITICAL NUMBER |
| Rural | One-Lane | 0.20 | 2 | 0.67 | 3 |
| | Two-Lane | 0.63 | 3 | 2.10 | 6 |
| | Three-Lane | 1.64 | 5 | 5.46 | 12 |
| | Four-Lane Divided (Non-Interstate or Parkway) | 1.36 | 5 | 4.54 | 11 |
| | Four-Lane Undivided | 2.30 | 7 | 7.67 | 15 |
| | Interstate | 2.21 | 7 | 7.37 | 15 |
| | Parkway | 0.74 | 3 | 2.46 | 7 |
| | All Rural | 0.68 | 3 | 2.26 | 7 |
| Urban | Two-Lane | 2.75 | 8 | 9.18 | 17 |
| | Three-Lane | 3.00 | 8 | 10.00 | 19 |
| | Four-Lane Divided (Non-Interstate or Parkway) | 3.48 | 9 | 11.59 | 21 |
| | Four-Lane Undivided | 4.27 | 10 | 14.24 | 24 |
| | Interstate | 8.56 | 17 | 28.53 | 43 |
| | Parkway | 1.28 | 5 | 4.26 | 10 |
| | All Urban* | 3.48 | 9 | 11.60 | 21 |

* Includes small number of miles of one-, five-, and six-lane highways.

TABLE 8. STATEWIDE RURAL RUN-OFF-THE-ROAD ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (1983-1987)

| HIGHWAY TYPE | TOTAL MILEAGE* | AADT | RUN-OFF-THE-ROAD ACCIDENT RATE (ACCIDENTS PER 100 MVM) |
|---|---|---|---|
| One-Lane | 328 | 200 | 183 |
| Two-Lane | 21,288 | 1,220 | 94 |
| Three-Lane | 15 | 2,280 | 132 |
| Four-Lane Divided (Non-Interstate or Parkway) | 293 | 7,460 | 33 |
| Four-Lane Undivided | 60 | 8,460 | 50 |
| Interstate | 576 | 18,380 | 22 |
| Parkway | 545 | 4,080 | 33 |
| All | 23,106 | 1,800 | 69 |

* Average for the five years.

TABLE 9. STATEWIDE URBAN RUN-OFF-THE-ROAD ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (1983-1987)

| HIGHWAY TYPE | TOTAL MILEAGE* | AADT | RUN-OFF-THE-ROAD ACCIDENT RATE (ACCIDENTS PER 100 MVM) |
|---|---|---|---|
| Two-Lane | 1,161 | 6,240 | 81 |
| Three-Lane | 11 | 9,350 | 59 |
| Four-Lane Divided (Non-Interstate or Parkway) | 258 | 18,940 | 34 |
| Four-Lane Undivided | 168 | 18,270 | 43 |
| Interstate | 159 | 44,530 | 35 |
| Parkway | 40 | 6,780 | 34 |
| All | 1,807 ** | 12,650 | 50 |

* Average for the five years.
** Includes small number of miles of one-,five-, and six-lane highway

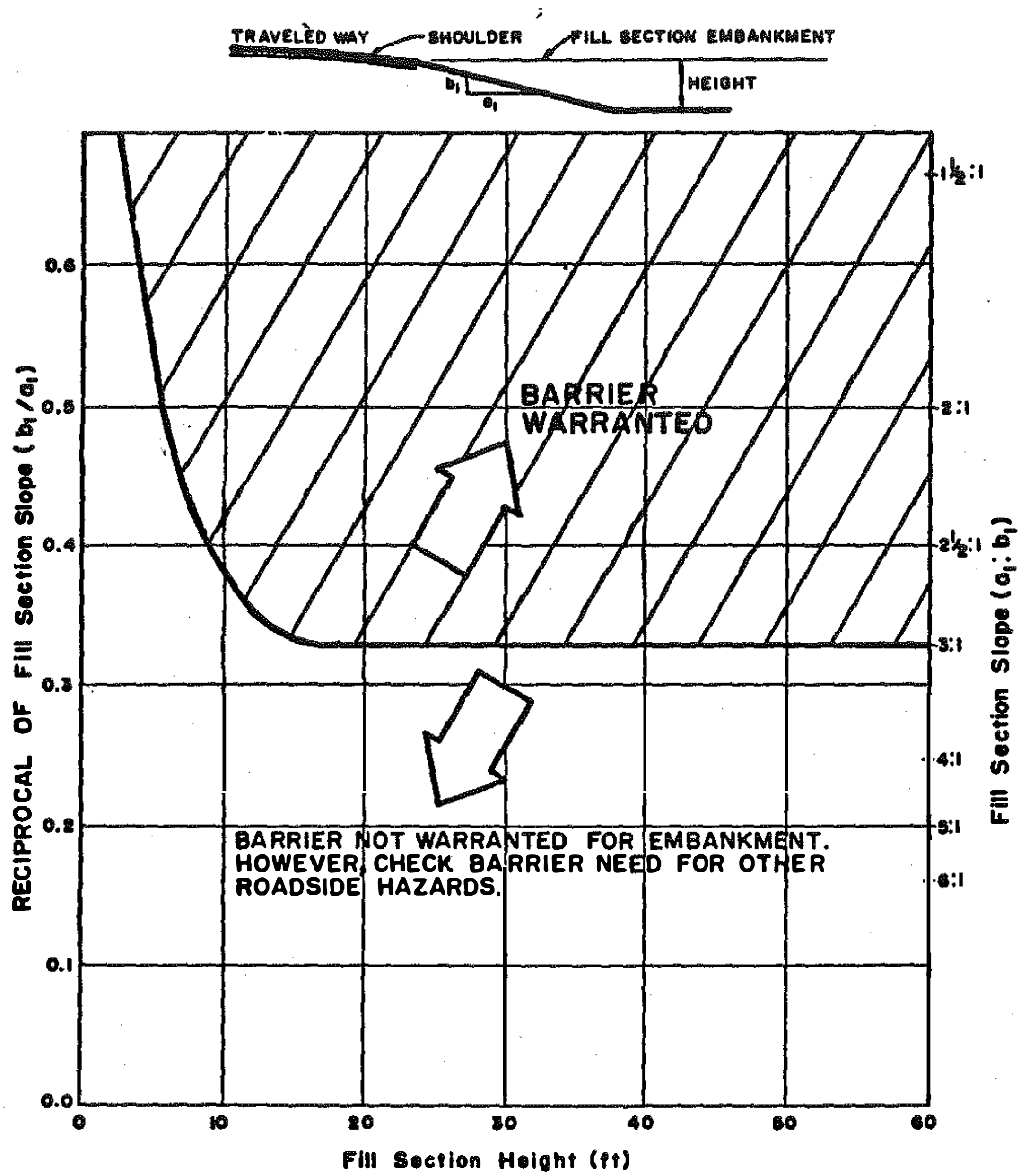



Figure 1. Barrier Warrants for Embankments (Roadside Design Guide - Reference 4).

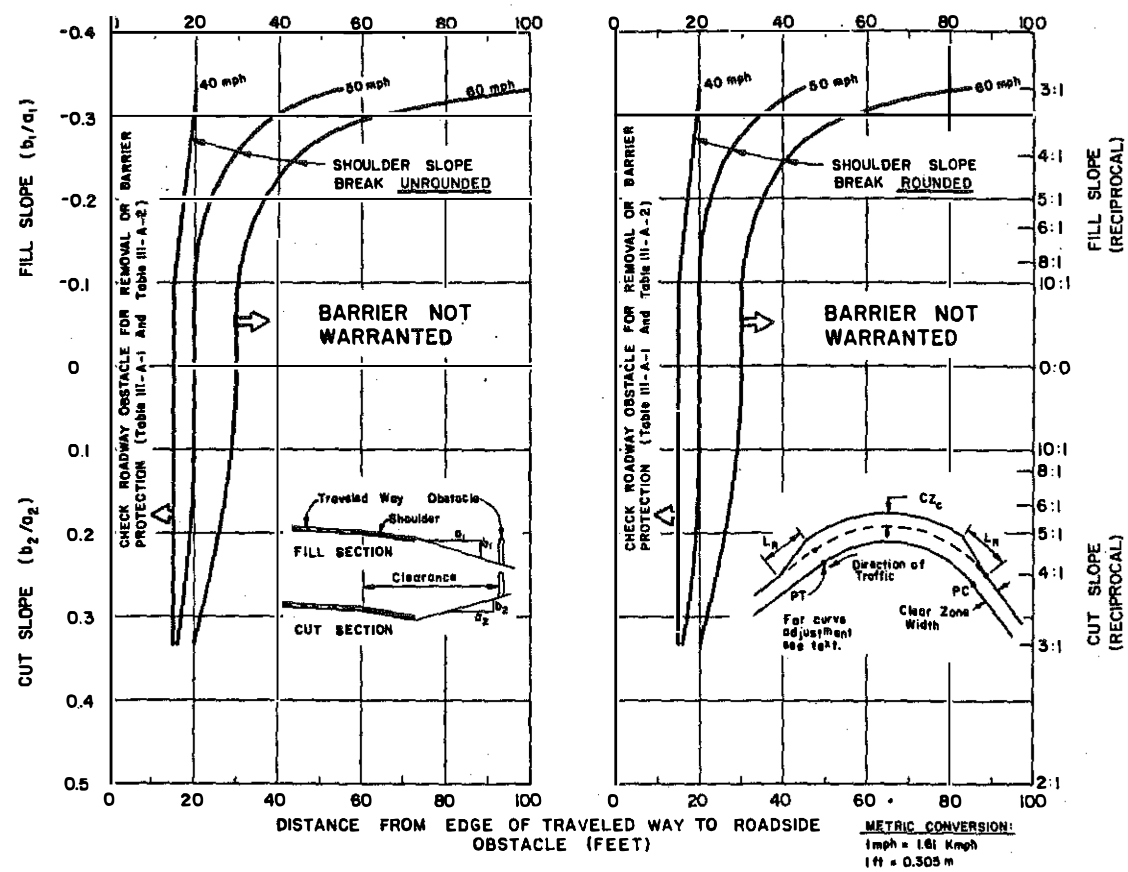



Figure 2. Clear Zone Criteria (Barrier Guide - Reference 1).

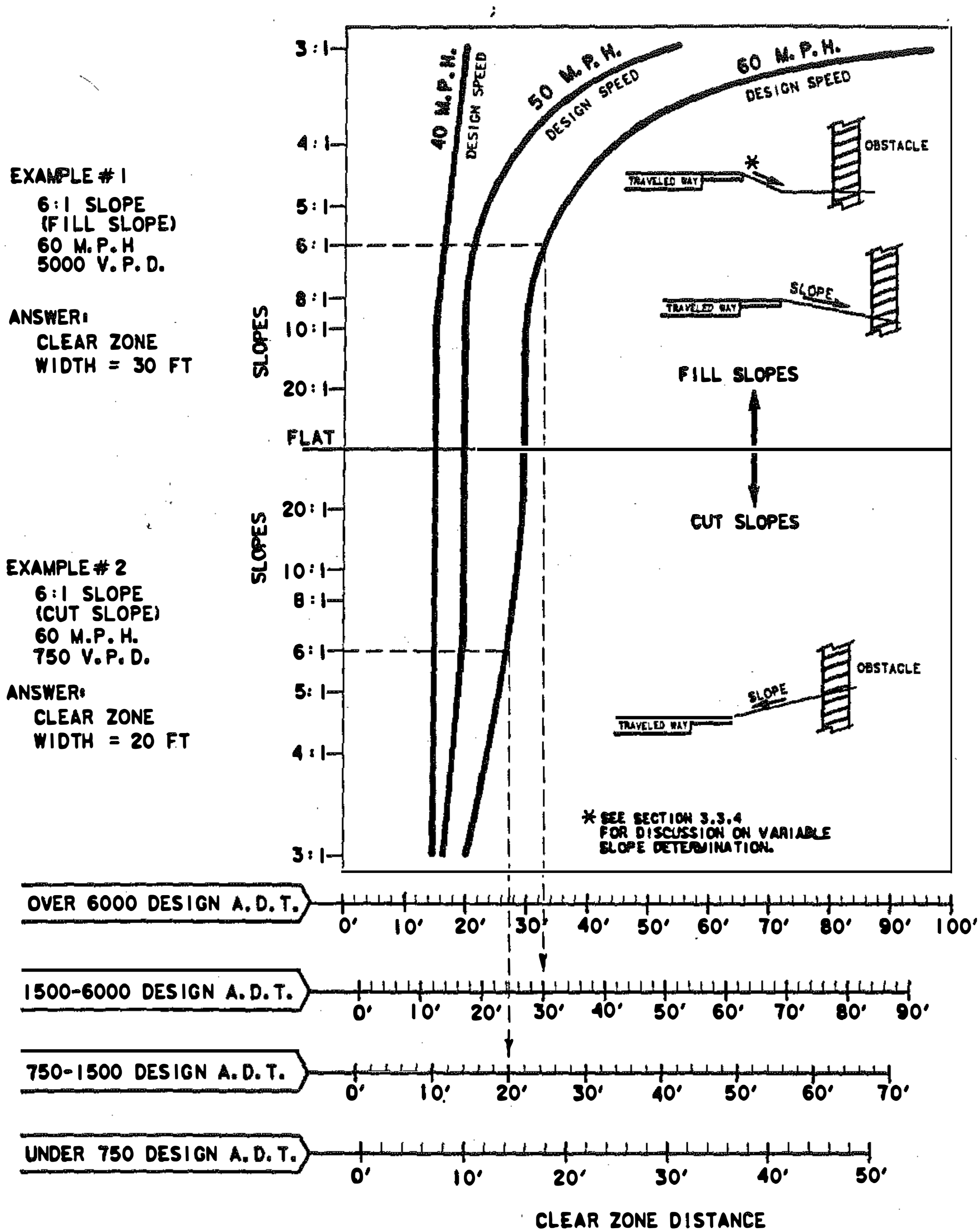



Figure 3. Clear Zone Criteria (Roadside Design Guide - Reference 4).

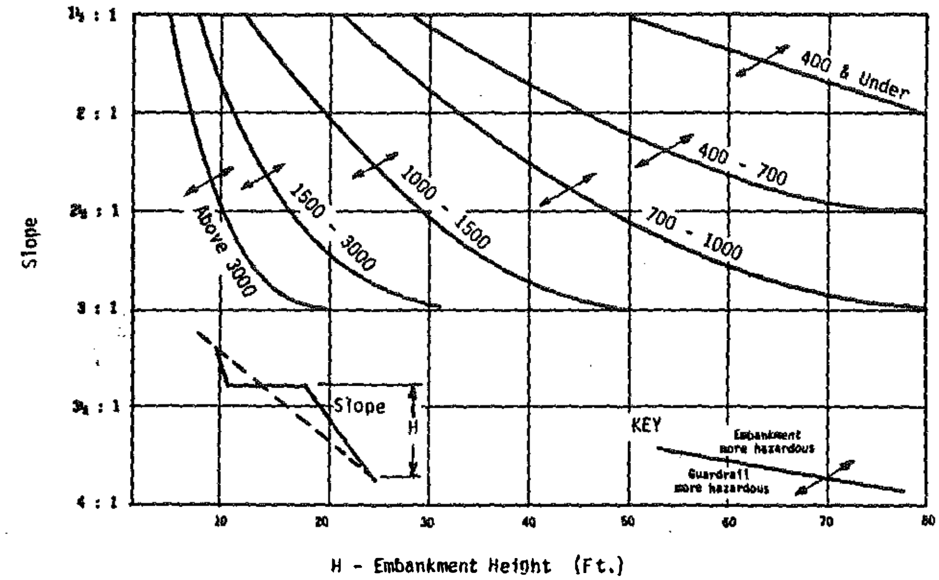



Figure 4. Modified Embankment Warrants Developed by a State (Roadside Design Guide - Reference 4).

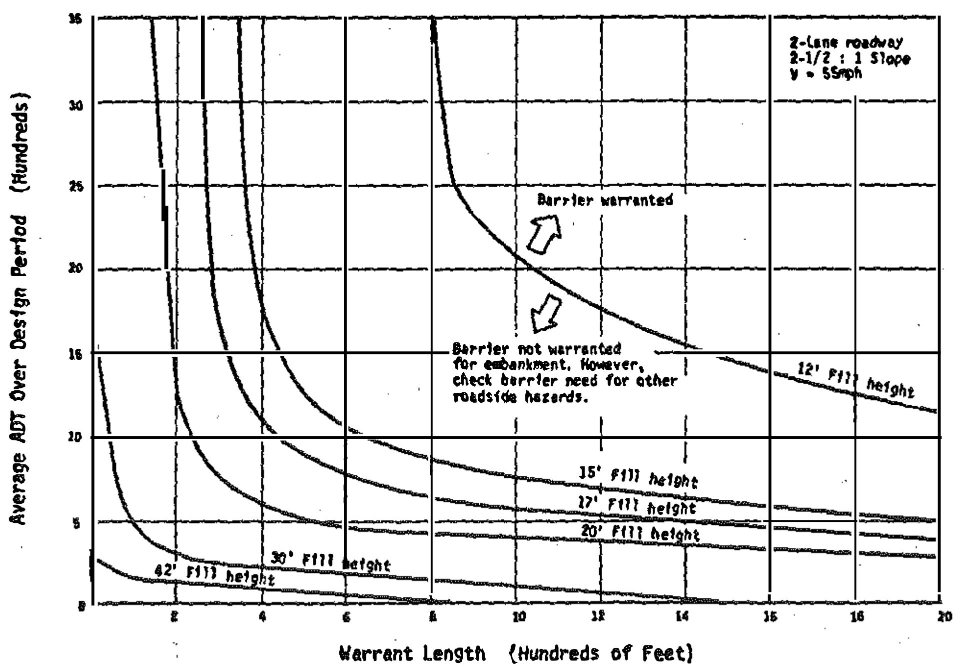



Figure 5. Embankment Warrants Considering Cost-Effectiveness and Site Conditions (Roadside Design Guide - Reference 4).

```
 1. FATALITY COST          =  $  1,500,000
 2. SEVERE INJURY COST     =  $     39,000
 3. MODERATE INJURY COST = $     12,000
 4. SLIGHT INJURY COST     =  $      6,000
 5. PDO LEVEL 2 COST       =  $      2,000
 6. PDO LEVEL 1 COST       =  $      2,000
 7. ENCROACHMENT MODEL =  ENCRATE  * (ADTeff ^ ENC.POWER) ENCROACHMENTS/MILE/YR
                       = 0.0728500 * (ADTeff ^ 0.593500 ) ENCROACHMENTS/MILE/YR
 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.

14. RESET ALL GLOBALS TO DEFAULT STARTUP VALUES.

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

SEVERITY INDEX versus COST RELATIONSHIP

| SEVERITY INDEX | COST |
|---|---|
| 0.0 | $ 0 |
| 0.5 | $ 2,000 |
| 1.0 | $ 2,522 |
| 2.0 | $ 3,580 |
| 3.0 | $ 20,810 |
| 4.0 | $ 53,190 |
| 5.0 | $ 130,920 |
| 6.0 | $ 283,580 |
| 7.0 | $ 465,700 |
| 8.0 | $ 763,050 |
| 9.0 | $ 1,132,860 |
| 10.0 | $ 1,500,000 |

Figure 6. Input Parameters for ROADSIDE Computer Program.

```
ROADSIDE - Version 4.1      05-19-1989     10:31:14       PAGE NUMBER   3

 1. TITLE:     clear zone

 2. INITIAL TRAFFIC VOLUME =    2,000 VEHICLES PER DAY
    TRAFFIC GROWTH RATE =  2.5 % PER YEAR    DESIGN YEAR ADT =     3,277
    LIMITING TRAFFIC VOLUME PER LANE  =   10,000

 3. UNDIVIDED HIGHWAY  LANE(S) OF ADJACENT TRAFFIC =   1.  LANE WIDTH = 11.0 FT.

 4. CURVATURE =   0.0 DEGREES          GRADE (PERCENTAGE) =   0.0

 5. INITIAL ENCROACHMENT FREQUENCY = 0.0728500 * (TVeff ^ 0.593500)
              TRAFFIC   BASELINE   CURVATURE   GRADE    USER    TOTAL
              VOLUME      ENC.      FACTOR     FACTOR   FACTOR   ENC.
    ADJACENT   1,000     4.3947      1.00       1.00     1.0     4.3947
    OPPOSING   1,000     4.3947      1.00       1.00     1.0     4.3947

 6. DESIGN SPEED = 50 MPH   ENCROACHMENT ANGLE =  15.2  SWATH WIDTH =  12.0

 7. LATERAL PLACEMENT (A)     =        22. FT.
    LONGITUDINAL LENGTH (L) =          1. FT.
    WIDTH OF OBSTACLE         =        1. FT.
                     ZONE1         ZONE2         ZONE3
    ADJACENT        0.0031        0.0381        0.0008   ENCROACHMENTS/YEAR
    OPPOSING        0.0031        0.0381        0.0008   ENCROACHMENTS/YEAR

 8. INITIAL COLLISION FREQUENCY =       0.007 IMPACTS PER YEAR
    EXPECTED IMPACTS OVER PROJECT LIFE =      0.172
    ADJACENT     CFT=  0.0047  CF1 =  0.0002  CF2 =  0.0043  CF3 =  0.0001
    OPPOSING     CFT=  0.0020  CF4 =  0.0001  CF5 =  0.0019  CF6 =  0.0001

 9. SEVERITY INDEX =   2.50          2.50        2.50        2.50         2.50
                     SIDEUP      SIDEDOWN   UP CORNER  DOWN CORNER      FACE
    ACCIDENT COST = $   12,195  $   12,195  $   12,195  $   12,195  $   12,195
    INITIAL COST/YEAR IMPACTS WITH  UPSTREAM SIDE      OF HAZARD = $         3
    INITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM SIDE    OF HAZARD = $         1
    INITIAL COST/YEAR IMPACTS WITH  UPSTREAM CORNER    OF HAZARD = $        53
    INITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM CORNER  OF HAZARD = $        23
    INITIAL COST/YEAR IMPACTS WITH  FACE               OF HAZARD = $         2
                                     TOTAL INITIAL ACCIDENT COST = $       81.

10. PROJECT LIFE =  20 YEARS        DISCOUNT RATE =  7.0 %
    KT =    10.594     KJ =     0.258     CRF =    0.094     KC   =  12.971

11. COST OF INSTALLATION            = $     2,000.
12. COST OF REPAIR  $ SU=      500  SD=     500  CU=     500   CD=      500   F=     500

13. MAINTENANCE COST PER YEAR       = $         0.
14. SALVAGE VALUE                   = $         0.

15. TOTAL PRESENT WORTH             = $     3,096.    ANNUALIZED $       292.
    HIGHWAY DEPARTMENT COST         = $     2,043.    ANNUALIZED $       193.

    INSTALLATION COST =               $     2,000.    ANNUALIZED $       189.
    REPAIR COST       =               $        43.    ANNUALIZED $         4.
    MAINTENANCE COST  =               $         0.    ANNUALIZED $         0.
    SALVAGE VALUE     =               $         0.    ANNUALIZED $         0.
    ACCIDENT COST     =               $     1,053.    ANNUALIZED $        99.
```

Figure 7. Example Input and Output from ROADSIDE Computer Program.

ORT NO. R1355
OGRAM NO. V0429
LECTION FACTOR: CTY ALL

KENTUCKY ACCIDENT REPORTING SYSTEM

DATE 02/08/89

PAGE 1

LOCATION RATES AND AVERAGE DAILY TRAFFIC VOLUMES
FROM 01/01/83 TO 12/31/87
CRF/COUNTY/ROUTE/MILEPOST

| UNTY | ROUTE | BEGINNING MILEPOST | ENDING MILEPOST | NUMBER OF ACCIDENTS | NUMBER OF LANES | CLASS | RURAL/URBAN DESIGNATOR | AVERAGE DAILY TRAFFIC | EPDO | ACCIDENT RATE | CRITICAL RATE | CRITICAL RATE FACTOR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 1681 | 011.000 | 011.900 | 14 | 2 | 2 | R | 157 | 25.0 | 48.86 | 7.27 | 6.72 |
| 76 | 0595 | 001.000 | 001.900 | 18 | 2 | 2 | U | 332 | 46.5 | 29.71 | 4.61 | 6.44 |
| 19 | 0547 | 001.100 | 002.000 | 39 | 2 | 2 | R | 1185 | 122.5 | 18.03 | 2.83 | 6.37 |
| 25 | 1927 | 000.300 | 001.200 | 23 | 2 | 2 | R | 578 | 75.0 | 21.80 | 3.80 | 5.74 |
| 56 | 0031W | 020.400 | 021.300 | 52 | 4 | 4 | U | 6730 | 102.0 | 4.23 | 0.80 | 5.29 |
| 25 | 0418 | 002.600 | 003.500 | 21 | 2 | 2 | R | 647 | 64.0 | 17.78 | 3.62 | 4.91 |
| 20 | 1659 | 003.100 | 004.000 | 13 | 2 | 2 | R | 281 | 43.5 | 25.35 | 5.34 | 4.75 |
| 76 | 1156 | 003.300 | 004.200 | 11 | 2 | 2 | R | 236 | 22.0 | 25.54 | 5.84 | 4.37 |
| 76 | 1983 | 001.900 | 002.800 | 11 | 2 | 2 | R | 305 | 33.0 | 19.76 | 5.13 | 3.85 |
| 056 | 0060A | 005.200 | 00 .100 | 50 | 4 | 4 | U | 10195 | 182.0 | 2.69 | 0.71 | 3.79 |
| 008 | 0338 | 001.200 | 002.100 | 15 | 2 | 2 | R | 584 | 59.0 | 14.07 | 3.78 | 3.72 |
| 059 | 1303 | 011.900 | 012.800 | 82 | 2 | 2 | U | 8480 | 220.0 | 5.30 | 1.43 | 3.71 |
| 037 | 1665 | 002.000 | 002.900 | 15 | 2 | 2 | R | 612 | 39.5 | 13.43 | 3.70 | 3.63 |
| 082 | 1882 | 002.500 | 003.400 | 14 | 2 | 2 | R | 586 | 64.0 | 13.09 | 3.78 | 3.46 |
| 008 | 0536 | 012.200 | 013.100 | 24 | 2 | 2 | R | 1479 | 52.5 | 8.89 | 2.61 | 3.41 |
| 120 | 1695 | 000.500 | 001.400 | 7 | 2 | 2 | R | 156 | 9.5 | 24.59 | 7.30 | 3.37 |
| 056 | 1020 | 009.400 | 010.300 | 69 | 4 | 4 | U | 18776 | 114.5 | 2.01 | 0.60 | 3.35 |
| 019 | 0547 | 004.200 | 005.100 | 27 | 2 | 2 | R | 1864 | 107.0 | 7.94 | 2.40 | 3.31 |
| 059 | 1829 | 002.000 | 002.900 | 28 | 2 | 2 | R | 1963 | 70.0 | 7.82 | 2.36 | 3.31 |
| 025 | 0418 | 003.600 | 004.500 | 16 | 2 | 2 | R | 836 | 37.0 | 10.49 | 3.25 | 3.23 |
| 034 | 1927 | 004.700 | 005.600 | 18 | 2 | 2 | R | 1019 | 51.0 | 9.68 | 3.00 | 3.23 |
| 059 | 1072 | 000.000 | 000.900 | 47 | 2 | 2 | U | 4877 | 118.5 | 5.28 | 1.64 | 3.22 |
| 056 | 1230 | 000.000 | 000.900 | 21 | 2 | 2 | U | 1493 | 54.0 | 7.71 | 2.40 | 3.21 |
| 120 | 0033 | 002.200 | 003.100 | 11 | 2 | 2 | R | 453 | 18.5 | 13.31 | 4.24 | 3.14 |
| 089 | 9001 | 057.500 | 058.400 | 16 | 4 | 6 | R | 3726 | 72.0 | 2.35 | 0.75 | 3.13 |
| 056 | 9064 | 004.200 | 005.100 | 166 | 4 | 6 | U | 58541 | 467.5 | 1.55 | 0.50 | 3.10 |

Figure 8. Example Printout of Locations with Run-Off-Road Critical Rate Factor.

:PORT NO. R1342 KENTUCKY ACCIDENT REPORTING SYSTEM DATE 02/08/89 PAGE 1

:OGRAM NO. V0430 RURAL ACCIDENT BUILDUP LISTING
:LECTION FACTOR: CTY 001 FROM 01/01/83 TO 12/31/87

| :UNTY | ROUTE | BEGINNING MILEPOST | ENDING MILEPOST | NUMBER OF ACCIDENTS | NUMBER OF LANES | CLASS | RURAL/URBAN DESIGNATOR | AVERAGE DAILY TRAFFIC | EPDO | ACCIDENT RATE (ACC/MVM) | CRITICAL RATE (ACC/MVM) | CRITICAL RATE FACTOR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 001 | 0061 | 12.100 | 13.000 | 07 | 02 | 2 | R | 1191 | 18.0 | 3.22 | 2.82 | 1.14 |

| CASE NUMBER | MILEPOST | DATE | DIRECTIONAL ANALYSIS | LIGHT | ROAD SURFACE | COLLISION TYPE | --NUMBER-- INJ | KILLED |
|---|---|---|---|---|---|---|---|---|
| 129261 | 12.100 | 12/25/85 | COLLISION WITH A FIXED OBJECT (SINGLE VEHICLE) | DAY | SNOW/ICE | FENCE | 0 | 0 |
| 110927 | 12.200 | 05/22/84 | COLLISION WITH A FIXED OBJECT (SINGLE VEHICLE) | DAY | DRY | FENCE | 0 | 0 |
| 190664 | 12.586 | 04/19/85 | RAN OFF ROADWAY (SINGLE VEHICLE) | DAY | DRY | DITCH | 2 | 0 |
| 016357 | 12.600 | 09/12/83 | COLLISION WITH A FIXED OBJECT (SINGLE VEHIC E) | DAY | DRY | GRDRL | 1 | 0 |
| 025343 | 12.600 | 12/22/83 | COLLISION WITH A FIXED OBJECT (SINGLE VEHICLE) | DAY | SNOW/ICE | GRDRL | 0 | 0 |
| 023642 | 12.800 | 12/03/83 | RAN OFF ROADWAY (SINGLE VEHICLE) | DAY | WET | DITCH | 0 | 0 |
| 127771 | 12.879 | 12/10/87 | COLLISION WITH A FIXED OBJECT (SINGLE VEHICLE) | DRK NO LTS | DRY | POLE | 0 | 0 |

Figure 9. Example Printout of Detailed Information Presented for Locations with Critical Rate Factors Greater than 1.0.

Figure 10. Point-System Rating, Accident History, Operational Characteristics, and Cross-Section.

1. Hazard Index rating of section based on number of accidents (Run-off-road accidents) (15 Points).

**Rural Sections**

| | Minimum Number of Accidents | | |
|---|---|---|---|
| Type of Road | 0.3 Mile | 1.0 Mile | Points |
| 1-Lane | 2 | 3 | 5 |
| | 3 | 4-5 | 10 |
| | > 5 | > 5 | 15 |
| 2-Lane | 3 | 6 | 5 |
| | 4-5 | 7-9 | 10 |
| | > 5 | > 9 | 15 |
| 3-Lane | 5 | 12 | 5 |
| | 6-8 | 13-18 | 10 |
| | > 8 | > 18 | 15 |
| 4-Lane Div. | 5 | 11 | 5 |
| | 6-8 | 12-17 | 10 |
| | > 8 | > 18 | 15 |
| 4-Lane Undiv. | 7 | 15 | 5 |
| | 8-11 | 16-23 | 10 |
| | > 11 | > 23 | 15 |
| Interstate | 7 | 15 | 5 |
| | 8-11 | 16-23 | 10 |
| | > 11 | > 23 | 15 |
| Parkway | 3 | 7 | 5 |
| | 4-5 | 8-11 | 10 |
| | > 5 | > 11 | 15 |

**Urban Sections**

| | Minimum Number of Accidents | | |
|---|---|---|---|
| Type of Road | 0.3 Mile | 1.0 Mile | Points |
| 2-Lane | 8 | 17 | 5 |
| | 9-12 | 18-26 | 10 |
| | > 12 | > 26 | 15 |
| 3-Lane | 8 | 19 | 5 |
| | 9-12 | 20-29 | 10 |
| | > 12 | > 29 | 15 |
| 4-Lane Div. | 9 | 21 | 5 |
| | 10-14 | 22-32 | 10 |
| | > 14 | > 32 | 15 |
| 4-Lane Undiv. | 10 | 24 | 5 |
| | 11-15 | 25-36 | 10 |
| | > 15 | > 36 | 15 |
| Interstate | 17 | 43 | 5 |
| | 18-26 | 44-65 | 10 |
| | > 26 | > 65 | 15 |
| Parkway | 5 | 10 | 5 |
| | 6-8 | 11-15 | 10 |
| | > 8 | > 15 | 15 |

2. Hazard Index rating of section based on accident rate (Run-off-road accidents) (15 Points).

**Rural Sections**

| Type of Road | Minimum Accident Rate* (Acc/100 MVM) | Points |
|---|---|---|
| 1-Lane | 183 | 15 |
| 2-Lane | 94 | 15 |
| 3-Lane | 132 | 15 |
| 4-Lane Div. | 33 | 15 |
| 4-Lane Undiv. | 50 | 15 |
| Interstate | 22 | 15 |
| Parkway | 33 | 15 |

**Urban Sections**

| Type of Road | Minimum Accident Rate* (Acc/100 MVM) | Points |
|---|---|---|
| 2-Lane | 81 | 15 |
| 3-Lane | 59 | 15 |
| 4-Lane Div. | 34 | 15 |
| 4-Lane Undiv. | 43 | 15 |
| Interstate | 35 | 15 |
| Parkway | 50 | 15 |

* Assign 15 points if Critical Rate Factor is 1.0 or greater.

3. Hazard Index rating based on traffic volume (10 Points).

| AADT | Points |
|---|---|
| 0-100 | 0 |
| 101-500 | 2 |
| 501-1,000 | 4 |
| 1,001-2,500 | 6 |
| 2,501-5,000 | 8 |
| > 5,000 | 10 |

4. Hazard Index rating based on highway speed (speed limit or prevailing speed if less than speed limit) (10 Points).

| Speed (mph) | Points |
|---|---|
| 25 or less | 0 |
| 26-35 | 3 |
| 36-45 | 5 |
| 46-55 | 7 |
| 56-65 | 10 |

5. Hazard Index rating based on roadway cross-section (50 Points).

a) Average lane and shoulder width (outside lane and shoulder width for roads with more than 2 lanes) (10 points)

| Width (feet) | Points by Volume Category 0-500 | 501-1,000 | 1,001-2,500 | >2,500 |
|---|---|---|---|---|
| more than 20 | 0 | 0 | 0 | 0 |
| 18-20 | 2 | 1 | 2 | 3 |
| 15-17 | 2 | 3 | 4 | 5 |
| 11-14 | 3 | 5 | 6 | 7 |
| 10 or less | 4 | 6 | 8 | 10 |

b) Average roadside recovery distance (including shoulder width) (10 Points)

| Distance (feet) | Points by Volume Category 0-500 | 501-1,000 | 1,001-2,500 | >2,500 |
|---|---|---|---|---|
| 30 or more | 0 | 0 | 0 | 0 |
| 20-29 | 2 | 1 | 2 | 3 |
| 10-19 | 2 | 3 | 4 | 5 |
| 5-9 | 3 | 5 | 6 | 7 |
| 4 or less | 4 | 6 | 8 | 10 |

c) Typical embankment slope (10 Points)

| Slope | Points by Volume Category 0-500 | 501-1,000 | 1,001-2,500 | >2,500 |
|---|---|---|---|---|
| 5:1 or flatter | 0 | 0 | 0 | 0 |
| 4:1 | 0 | 1 | 2 | 3 |
| 3:1 | 2 | 3 | 4 | 5 |
| 2:1 | 3 | 5 | 6 | 7 |
| 1:1 or steeper | 4 | 6 | 8 | 10 |

d) Typical embankment height (10 Points)

| Height (feet) | Points by Volume Category 0-500 | 501-1,000 | 1,001-2,500 | >2,500 |
|---|---|---|---|---|
| 5 or less | 0 | 0 | 0 | 0 |
| 6-10 | 0 | 1 | 2 | 3 |
| 11-20 | 2 | 3 | 4 | 5 |
| 21-30 | 3 | 5 | 6 | 7 |
| more than 30 | 4 | 6 | 8 | 10 |

e) Culvert Headwall or Culvert Opening Within 5 Feet of Travel Lane
(5 Points)

Yes - 5 Points
No - 0 Points

f) Average Roadside Hazard Rating (5 Points)
(Based on a scale of 1 to 5 representing the degree of hazard associated with a 0.3-mile section)

| Subjective Rating | Points |
|---|---|
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |

6. Summary of Points

a) _____ Number of Accidents
b) _____ Accident Rate
c) _____ Traffic Volume
d) _____ Highway Speed
e) _____ Lane and Shoulder Width
f) _____ Roadside Recovery Distance
g) _____ Embankment Slope
h) _____ Embankment Height
i) _____ Culvert Presence
j) _____ Subjective Roadside Hazard Rating

_____ TOTAL

Figure 11. Road Cross-Section Survey Form and Condition Description

1. Date: _________ (Month, Day, Year) 2. County: _____________

3. District: _________ 4. Route Number: _________

5. Milepoint Beginning: _________ Ending: _________ Length: _________

6. Area Type (Check): _____ Rural _____ Urban

7. Terrain Condition (Check One): _____ Flat _____ Rolling _____ Mountainous

8. Average Daily Traffic: _________

9. Speed Limit or Prevailing Speed if Less than Speed Limit:
_____ 25 mph or less, _____ 26-35, _____ 36-45, _____ 46-55, _____ 56-65

10. Number of Lanes (Both Directions): _________

11. Average Lane and Shoulder Width (Feet) (Round Down to Nearest Whole Number):
_____ more than 20, _____ 18-20, _____ 15-17, _____ 11-14, _____ 10 or less

12. Average Roadside Recovery Distance (Feet) (Excluding Culverts) (Including Shoulder Width):
_____ 30 or more, _____ 20-29, _____ 10-19, _____ 5-9, _____ 4 or less

13. Typical Embankment Slope:
_____ 5:1 or flatter, _____ 4:1, _____ 3:1, _____ 2:1, _____ 1:1 or steeper

14. Typical Embankment Height (Feet):
_____ 5 or less, _____ 6-10, _____ 11-20, _____ 21-30, _____ more than 30

15. Culvert Headwall or Culvert Opening Within 5 Feet of Travel Lane:
_____ Yes _____ No

16. Average Roadside Hazard Rating:
_____ 1, _____ 2, _____ 3, _____ 4, _____ 5

17. Number of Run-Off-Road Accidents in 0.3-Mile Section (5-Year Period): _____
Critical Number of Run-Off-Road Accidents _____

18. Run-Off-Road Accident Rate for 0.3-Mile Section (5-Year Period): _____
Critical Run-Off-Road Accident Rate: _____

19. Critical Run-Off-Road Accident Rate Factor: _____

20. Number of Fatalities, Injuries, and PDO Accidents in 0.3-Mile Section (Run-Off-Road) (5-Year Period):
_____ Fatalities
_____ Injuries
_____ PDO Accidents

PORT NO. R1355
OGRAM NO. V0429
LECTION FACTOR: CT ALL

KENTUCKY ACCIDENT REPORTING SYSTEM

LOCATION RATES AND AVERAGE DAILY TRAFFIC VOLUMES
FROM 01/01/84 TO 12/31/88
COUNTY/ROUTE/MILEPOST

DATE 05/10/89



| UNTY | ROUTE | BEGINNING MILEPOST | ENDING MILEPOST | NUMBER OF ACCIDENTS | NUMBER OF LANES | CLASS | RURAL/URBAN DESIGNATOR | AVERAGE DAILY TRAFFIC | EPDO | ACCIDENT RATE | CRITICAL RATE | CRITICAL RATE FACTOR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 001 | 0055 | 005.200 | 005.400 | 3 | 2 | 2 | R | 1001 | 3.0 | 1.64 | 1.56 | 1.05 |
| 001 | 0055 | 006.200 | 006.400 | 3 | 2 | 2 | R | 1425 | 8.0 | 1.15 | 1.31 | 0.88 |
| 001 | 0055 | 007.400 | 007.600 | 3 | 2 | 2 | R | 1449 | 8.0 | 1.13 | 1.30 | 0.87 |
| 001 | 0055 | 010.700 | 010.900 | 3 | 2 | 2 | R | 8370 | 14.0 | 0.20 | 0.66 | 0.30 |
| 001 | 0055 | 011.000 | 011.200 | 5 | 2 | 2 | R | 8840 | 5.0 | 0.31 | 0.65 | 0.48 |
| 001 | 0055 | 011.700 | 011.900 | 3 | 2 | 2 | R | 6452 | 11.5 | 0.25 | 0.71 | 0.35 |
| 001 | 0055 | 013.100 | 013.300 | 3 | 2 | 2 | R | 3117 | 14.0 | 0.53 | 0.94 | 0.56 |
| 001 | 0061 | 013.700 | 013.900 | 10 | 2 | 2 | R | 2274 | 43.0 | 2.41 | 1.07 | 2.25 |
| 001 | 0061 | 014.000 | 014.200 | 8 | 2 | 2 | R | 2274 | 27.5 | 1.93 | 1.07 | 1.80 |
| 001 | 0061 | 016.000 | 016.200 | 3 | 2 | 2 | R | 2857 | 5.5 | 0.58 | 0.97 | 0.60 |
| 001 | 0061 | 016.300 | 016.500 | 3 | 2 | 2 | R | 3156 | 3.0 | 0.52 | 0.93 | 0.56 |
| 001 | 0061 | 016.600 | 016.800 | 3 | 2 | 2 | R | 3456 | 3.0 | 0.48 | 0.90 | 0.53 |
| 001 | 0061 | 016.900 | 017.100 | 4 | 2 | 2 | R | 3456 | 6.5 | 0.63 | 0.90 | 0.70 |
| 001 | 0061 | 017.700 | 017.900 | 3 | 2 | 2 | R | 1796 | 11.5 | 0.92 | 1.18 | 0.78 |
| 001 | 0061 | 018.900 | 019.100 | 3 | 2 | 2 | R | 1796 | 3.0 | 0.92 | 1.18 | 0.78 |
| 001 | 0061 | 020.500 | 020.700 | 4 | 2 | 2 | R | 1796 | 6.5 | 1.22 | 1.18 | 1.03 |
| 001 | 0080 | 007.300 | 007.500 | 4 | 2 | 2 | R | 750 | 4.0 | 2.92 | 1.81 | 1.61 |
| 001 | 0080 | 007.800 | 008.000 | 3 | 2 | 2 | R | 750 | 14.0 | 2.19 | 1.81 | 1.21 |
| 001 | 0080 | 012.000 | 012.200 | 3 | 2 | 2 | R | 7842 | 14.0 | 0.21 | 0.67 | 0.31 |
| 001 | 0080 | 020.100 | 020.300 | 3 | 2 | 2 | R | 1957 | 5.5 | 0.84 | 1.14 | 0.74 |
| 001 | 0206 | 001.300 | 001.500 | 3 | 2 | 2 | R | 2262 | 8.0 | 0.73 | 1.07 | 0.68 |
| 001 | 0206 | 009.700 | 009.900 | 3 | 2 | 2 | R | 945 | 14.0 | 1.74 | 1.61 | 1.08 |
| 001 | 0439 | 001.300 | 001.500 | 6 | 2 | 2 | R | 3177 | 31.5 | 1.03 | 0.93 | 1.11 |
| 001 | 0551 | 002.100 | 002.300 | 5 | 2 | 2 | R | 1248 | 24.5 | 2.20 | 1.40 | 1.57 |
| 001 | 0551 | 005.000 | 005.200 | 4 | 2 | 2 | R | 344 | 9.0 | 6.37 | 2.79 | 2.28 |
| 001 | 0704 | 002.900 | 003.100 | 3 | 2 | 2 | R | 91 | 16.5 | 18.06 | 6.64 | 2.72 |

Figure 12. Example Printout of Locations in Order of County, Route and Milepoint.

# APPENDIX A

# METHODS USED TO ADDRESS INADEQUATE GUARDRAIL HEIGHT

## GUARDRAIL HEIGHT

Adequate guardrail height is an integral part of the standard guardrail system to assure redirectional capabilities and to prevent vaulting. The current standard height to the tope of the rail for W-beam guardrail with 6" x 8" wood posts or W6 x 8.5 steel posts is 27 inches. Information presented in the AASHTO "Guide for Selecting, Locating, and Designing Traffic Barriers" recommends that height deviations greater than 3 inches warrant height corrections.

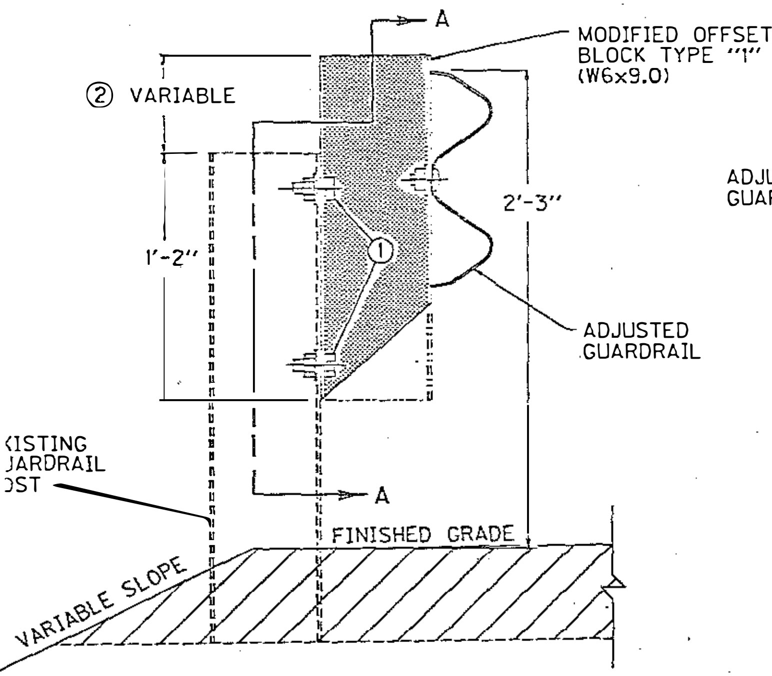
Frequent causes of incorrect rail height are uneven embankment settlement; pavement overlays; sod, soil and debris build-up on the shoulder; and improper installation. Problems with guardrail height in Kentucky are the result of the effective height from ground surface to top of rail being less than the standard of 27 inches. A Detail Sheet has been prepared by the Kentucky Department of Highways which provides information to assist in the field alteration of guardrail to raise the effective height. The "Modified Offset Block Type 1" is designed to permit raising the height of the guardrail a maximum of 9 inches. A copy of the Detail Sheet is attached and may be considered as an alternate procedure for corrective action when inadequate guardrail height exists. Following is a list of alternate procedures which may be used to address low guardrail height.

1. Use of an adjustable blockout so that the effective height of the guardrail can be raised without removing the posts. This concept has been used in Kentucky; however, it appears that more widespread use is occurring in some other states. For example, Illinois has adopted an adjustable blockout design that permits raising the guardrail as much as 3 inches on two occasions that results in a total height increase of 6 inches. The blockout design is longer than the typical blockout, with the front side 13" long and the back side 18-7/8" long; connected at an angle of 45 degrees.

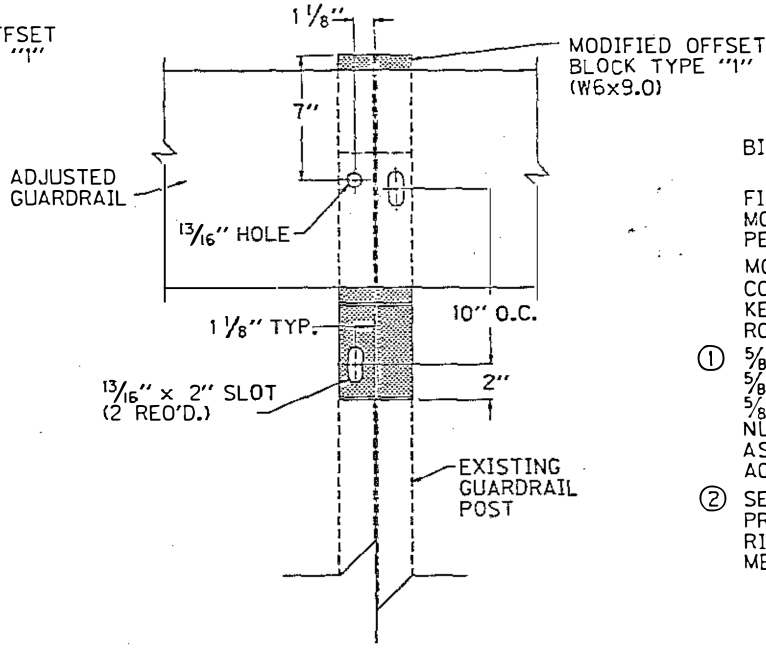
2. Another alternative is to use the concept of removing and reinstalling the entire guardrail system when the height is inadequate. This involves removing rail, posts, and blockouts; and then driving the posts back into the ground at a point near the original installation. The result is an installation at proper height and current standards otherwise, assuming that the hardware is adequate and meets current standards. This solution could be improved with the installation of adjustable blockouts, so that future needs to raise the guardrail could be accomplished with less effort.

3. Overall adjustment of guardrail height by lifting the system the desired height is an alternative that apparently has been used on a limited basis. This procedure involves lifting the posts and rail by using some type of equipment with a hydraulic lift such as a high lift or front-end loader. Disadvantages of this system are that simply lifting the posts from the ground to the proper height does not insure that the height will be maintained for any significant period of time (it is likely that uneven post settlement will occur without redriving the posts). In addition, the procedure to lift the posts and rail is cumbersome and possibly difficult to accomplish.

| COUNTY OF | FISCAL YEAR | SHEET NO. | TOTAL SHEETS |
|---|---|---|---|
| | | | |




SIDE VIEW




FRONT VIEW

## NOTES

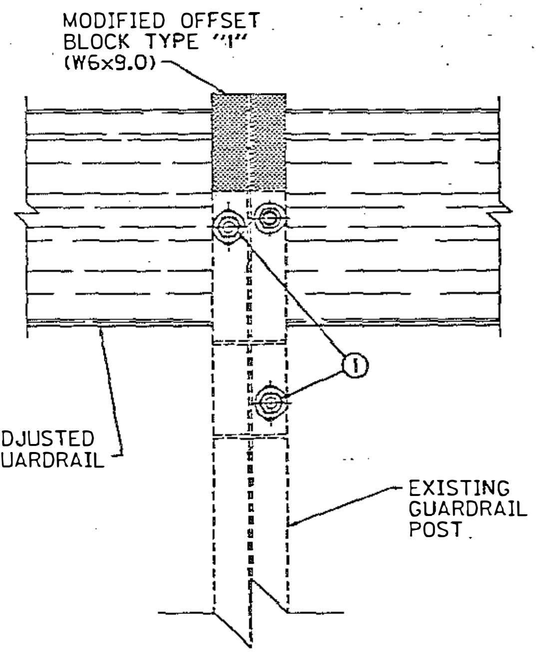
BID ITEM AND UNIT TO BID:
ADJUSTING GUARDRAIL -- LINEAR FOOT

FIELD DRILLING AND CUTTING OF THE MODIFIED OFFSET BLOCK WILL NOT BE PERMITTED.

MODIFIED OFFSET BLOCK TYPE 1 SHALL COMPLY WITH SECTION 814 OF THE CURRENT KENTUCKY STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION.

① 5/8" x 1 1/2" HEX HEAD BOLTS (2 REQUIRED), 5/8" FLAT WASHERS (4 REQUIRED), 5/8" HEX NUTS (2 REQUIRED). THE BOLTS, NUTS AND WASHERS SHALL COMPLY WITH ASTM A325 AND BE GALVANIZED IN ACCORDANCE WITH ASTM A153.

② SEE ELSEWHERE IN THE PLANS OR PROPOSEL FOR DIMENSION. MAXIMUM RISE OF 9 INCHES PERMITTED BY THIS METHOD.




SECTION A-A

**KENTUCKY DEPARTMENT OF HIGHWAYS**

MODIFIED OFFSET BLOCK TYPE "1"

SUBMITTED E. B. Drake 2/10/88
FOR DIRECTOR DIVISION OF DESIGN DATE
APPROVED
STATE HIGHWAY ENGINEER DATE

# APPENDIX B

## SUMMARY OF STATE SURVEY - WARRANTS AND GUIDELINES FOR INSTALLATION OF GUARDRAIL

## SUMMARY OF STATES

## GUIDELINES FOR INSTALLATION OF GUARDRAIL

**Alabama**

1. clear zone width criteria down to under 250 ADT (same as Figure 3.1 in Roadside Design Guide)
2. embankment criteria (from Barrier Guide) applies to higher traffic volumes (over 3,000 ADT) and higher design speed rural roads with statement that, in general, it is not cost effective to require guardrail on lower traffic volume roads at every warranting location,
3. no provision for lower guardrail standards

**Alaska**

1. embankment criteria curve based on accident data
2. warrant criteria given as function of ADT by:
   a. height of fill and slope,
   b. water at toe of fill,
   c. alignment (curvature),
   d. road width,
   e. grade,
   f. climatic conditions.
3. various types of guardrail (use weak post with no blockout but maintain clear distance behind)

**Arkansas**

turned down is standard end treatment

**Arizona**

flared BCT used at the end of "length of need" in rural locations with a BCT attenuator assembly used where an opening occurs along the "length of need"

**California**

1. use BCT where adequate recovery distance present (allow minimum BCT flare of 2 feet)
2. no provision noted for no blockout

**Colorado**

1. use Barrier Guide as primary guideline for warrants and installations
2. use W-beam with separate specifications for local roads and streets but no difference in post spacing or blockout requirements

**Connecticut**

1. has detailed "Manual for Selecting, Locating, and Designing Guide Railing and Traffic Barriers"
2. has warrants based on: a) embankments and b) clear zone
3. lists application of various types of guardrail
4. clear zone distance varies with operating speed with 30 feet for 50 mph and over, 25 feet for 30 to 50 mph, and 20 feet for up to 30 mph

| | | |
|---|---|---|
| Delaware | | developing a design manual to include the warrants, use, and choice of barriers |
| Florida | 1. | clear recovery area varied from a maximum of 30 feet for interstates and undivided highways with a design speed of 50 mph or more with a projected ADT of 1,600 or above to 20 feet for undivided highways with a design speed of 50 mph or more with a projected ADT of less than 1,600 (14 feet for projected ADT under 750) to 18 feet where right-of-way permits for divided or undivided roads with a design speed of 35 to 45 mph (14 foot minimum) to a minimum of four feet from the face of curb in curb and gutter sections with design speed of 45 mph or less. |
| | 2. | different guardrail designs not given for lower class highways |
| Georgia | 1. | figure from Barrier Guide for higher volume and speed roads for fill embankment warrant |
| | 2. | other figures for lower volume roads for warrants concerning slope and fill height (figures ranging from an ADT of 1,500 to 3,000 down to 400 or less) |
| | 3. | clear zone width criteria same as Figure 3.1 in Roadside Design Guide |
| | 4. | examples of roadside obstacles warranting guardrail include rough rock cuts, large boulders, water over two feet in depth, lines of trees with over six-inch diameter, drop-off with slope steeper than 1:1 and depth over two feet, bridge piers, culverts, and post with area over 50 square inches |
| | 5. | standards for design of guardrail given by type of highway but few differences |
| Hawaii | 1. | use Barrier Guide for design and use of guardrail |
| Idaho | 1. | buried end treatment preferred |
| | 2. | four foot flare required for BCT |
| Illinois | | reduced BCT flare to 1 foot minimum |
| Indiana | 1. | BCT only used where four-foot flare can be obtained; otherwise used buried end |
| | 2. | no indication of different standards for various highway types |
| Iowa | 1. | use Barrier Guide for warrants |
| | 2. | BCT is only end treatment used where terminal is exposed to oncoming traffic |
| Kansas | 1. | use BCT on new construction and reconstruction of high-volume roads |
| | 2. | use turned-down where right of way prevents 4 foot offset |

| | | |
|---|---|---|
| | 3. | no indication of different guardrail design for various classes of highway |
| Louisiana | 1. | embankment warrant from Barrier Guide |
| | 2. | minimum design standard are given based on highway class, design speed, and ADT |
| | 3. | criteria given for adding guardrail at bridges on overlay or widening projects |
| Maine | 1. | turned down or BCT end treatment used on interstates |
| | 2. | flared, non-breakaway end treatment used on primary and secondary two-lane roads |
| Maryland | 1. | use Barrier Guide for warrants |
| | 2. | use blocked out W-beam with no mention of different standards for lower types of highways |
| Massachusetts | | standards do not show different specifications by highway type |
| Michigan | 1. | warrants are same for all roads, regardless of traffic volume |
| | 2. | have "Type A" guardrail with 12 foot, 6 inch spacing and no blockout in addition to other guardrail with 6 foot, 3 inch spacing with blockout |
| Minnesota | 1. | provision for post spacing of 12 feet, 6 inches where speed under 50 mph |
| | 2. | clear zones given as function of speed and side slope; adjustments are made for curvature and ADT |
| | 3. | nontraversable hazards within the clear zone warranting guardrail include rough rock cuts, large boulders, water more than two feet in depth, and shoulder drop-off with slope steeper than 1:1 and height over two feet |
| Mississippi | 1. | use Barrier Guide warrants |
| | 2. | in fill sections install guardrail when slope greater than 3:1 and depth of fill greater than 10 feet |
| | 3. | acceptable end treatments and BCT, buried, and crash cushion |
| Missouri | | did not use BCT, used turned down |
| Montana | 1. | no warrants for type of end treatment to use |
| | 2. | prefer slope embedment end treatment over the BCT |
| Nebraska | 1. | use BCT or modified turned down, |
| | 2. | on new construction, BCT installed out to desirable clear zone distance if lateral clear distance cannot be obtained |

| | | |
|---|---|---|
| Nevada | 1. | no indication of modifying design standards for various classes of roads |
| New Hampshire | 1. | use embankment warrant from Barrier Guide but in rural condition, guardrail typically used on any slope steeper than 4:1 |
| | 2. | guardrails sometimes required to protect vehicles from deep ditches, water, or other hazards when foreslope is 4:1 or flatter |
| New Jersey | | use BCT if four-foot flare can be obtained; otherwise, use 25-foot rail element |
| New York | 1. | for slope of 3:1 or flatter, guardrail not required; need guardrail of 2:1 with embankment height of 6 feet |
| | 2. | clear zone of 30 feet for speeds of 50 mph or more, 25 feet for 40 mph, and 20 feet for 30 mph |
| | 3. | gives recommended action for various fixed objects |
| | 4. | gives selection criteria for type of guardrail based on available deflection distance |
| New Mexico | | use both BCT and turned down |
| North Carolina | | use a cost effectiveness analysis for warrants using a computer program available |
| North Dakota | | use Barrier Guide for warrants and design |
| Ohio | | turned down end used based on volume (less than 1,000 ADT) and design speed (less than 50 mph) whenever shoulder width is insufficient to provide standard flare; also use BCT |
| Oklahoma | 1. | use Barrier Guide as guide for warrants |
| | 2. | use turned down end treatment rather than BCT |
| Oregon | | warrants based on Barrier Guide |
| Pennsylvania | 1. | warrants based on Barrier Guide |
| | 2. | strong post and weak post (with no blockout) are used |
| Rhode Island | | use Barrier Guide for guidance |
| South Carolina | | standard metal guardrail with 6 foot, 3 inch spacing with blockout with no indication of change in design for lower highway classifications |
| South Dakota | 1. | no information concerning warrants |
| | 2. | BCT is only end treatment used |

| | | |
|---|---|---|
| Tennessee | 1. | refer to Barrier Guide for guidance |
| | 2. | for repair of damage to old sections of guardrail, generally replace in-kind without upgrading to current standards |
| Texas | 1. | turned down end used on all types of highways |
| | 2. | no information concerning warrants for guardrail installation |
| Utah | | use Barrier Guide for fill section embankment and clear zone warrants |
| Vermont | 1. | design speed is used to select end treatment; BCT used for design speed over 40 mph |
| | 2. | use flared, nonbreakaway end where design speed of 40 mph or less |
| Virginia | 1. | use Barrier Guide for guidance for installations |
| | 2. | has strong post (with blockout) and weak post (no blockout) systems |
| Washington | 1. | no information concerning guardrail warrants |
| | 2. | in new construction and reconstruction, preferred end treatment if to bury end in cut slope |
| West Virginia | | based on design year ADT and design speed, guardrail would be either at: a) 6 feet, 3 inches spacing with blocks, b) 12 feet, 6 inches spacing with blocks, or c) 12 feet, 6 inches spacing without blocks; also end treatment would be either a BCT, cut slope terminal, or flared not anchored |
| Wisconsin | 1. | turned down end treatment typical |
| | 2. | when use BCT, have two foot minimum offset |
| Wyoming | 1. | use Barrier Guide warrant for embankments |
| | 2. | normally locate end at least 30 feet from pavement (in some cases, use minimum of four-foot parabolic flare for BCT) |

# APPENDIX C

# LOW SERVICE LEVEL AND WEAK POST GUARDRAIL SYSTEMS

# DEVELOP PERFORMANCE STANDARDS AND HARDWARE FOR LOW SERVICE LEVEL GUARDRAIL SYSTEM

FINAL REPORT

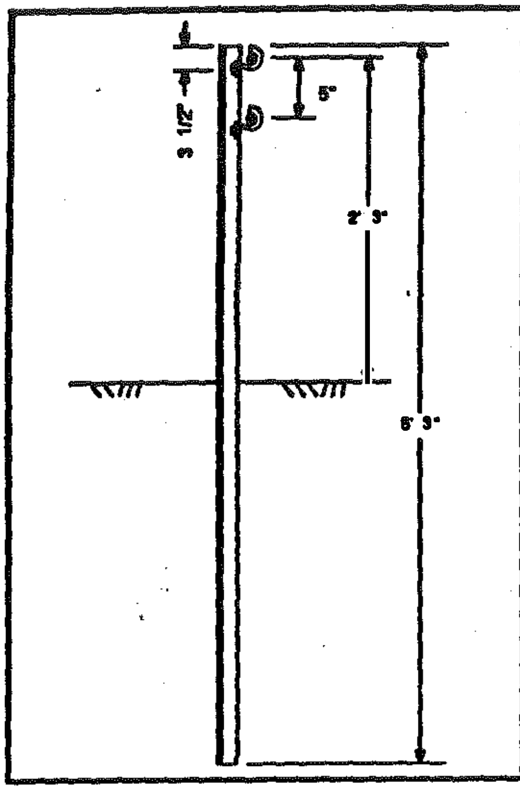
Prepared For

National Cooperative Highway Research Program
Transportation Research Board
National Research Council

C. E. Kimball
K. L. Hancock
Southwest Research Institute
San Antonio, Texas

Southwest Research Institute Project 06-8615

January 1989

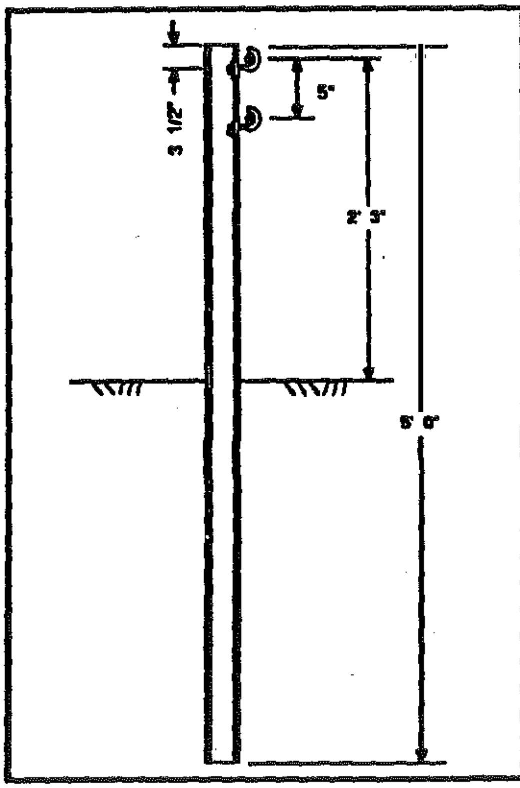



**FRACTIONAL SERVICE LEVEL**

**OPTION A**

**(FSLA)**

| | |
|---|---|
| **Beam:** | **2ea. 3/4 in cables** |
| **Post:** | **4 #/ft Steel Hat Section** |
| **Post Spacing:** | **16 ft - 0 in** |
| **Bolt:** | **5/16 in dia.** |



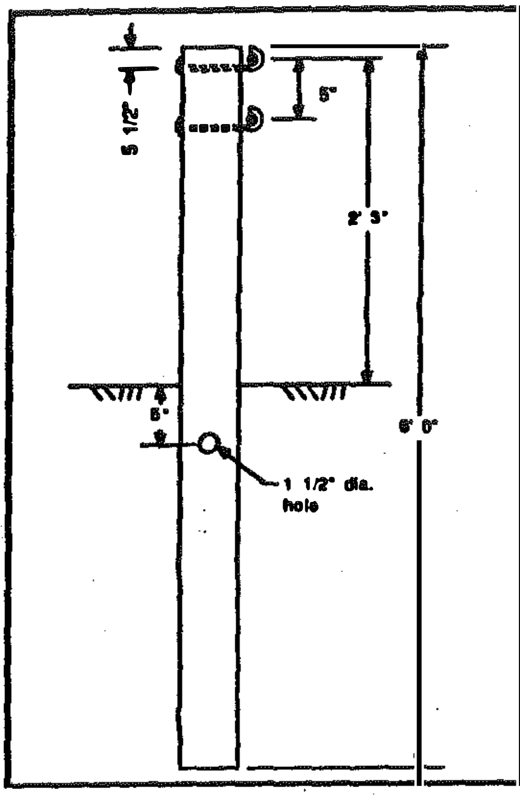

**FRACTIONAL SERVICE LEVEL**

**OPTION A (ALT)**

**(FSLA ALT)**

| | |
|---|---|
| **Beam:** | **2ea. 3/4 in cables** |
| **Post:** | **S3 X 5.7 Steel** |
| **Post Spacing:** | **16 ft - 0 in** |
| **Bolt:** | **5/16 in dia.** |

FRACTIONAL SERVICE LEVEL BARRIER SYSTEM CONFIGURATIONS

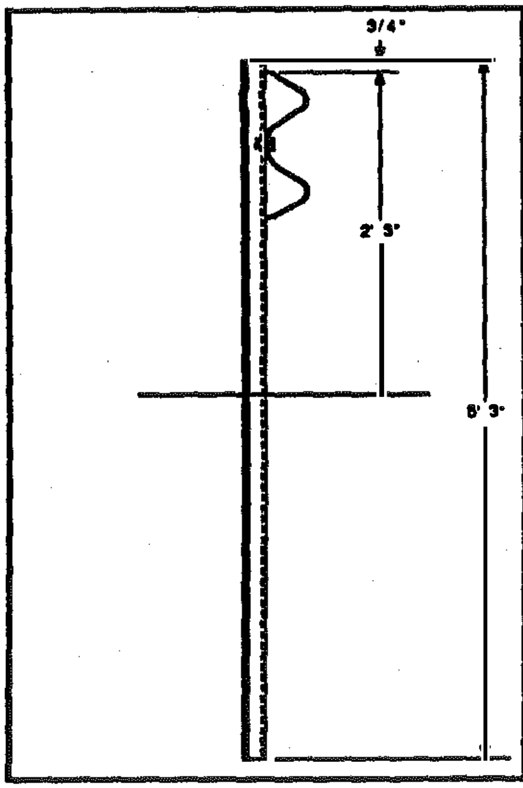



FRACTIONAL SERVICE LEVEL

OPTION B

(FSLB)

| | |
|---|---|
| Beam: | 2ea. 3/4 in cables |
| Post: | 5 1/2 in dia. wood |
| Post Spacing: | 16 ft - 0 in |
| Bolt: | 5/16 in dia. |



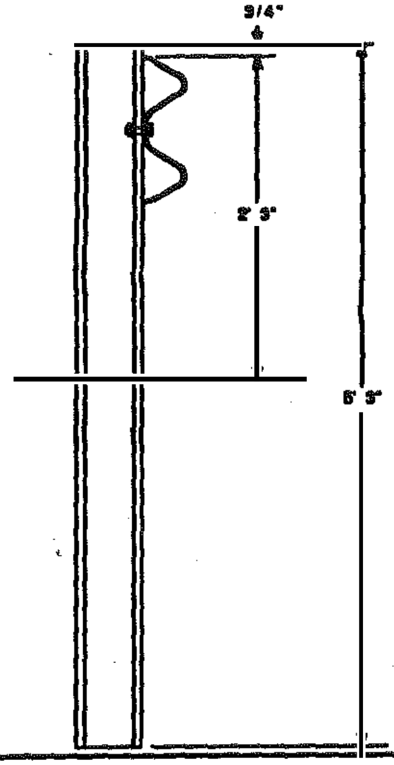

FRACTIONAL SERVICE LEVEL

OPTION C

(FSLC)

| | |
|---|---|
| Beam: | 12 ga. W-beam |
| Post: | 4 #/ft Steel Hat Section |
| Post Spacing: | 12 ft - 6 in |
| Bolt: | 5/16 in dia. |

FRACTIONAL SERVICE LEVEL BARRIER SYSTEM CONFIGURATIONS

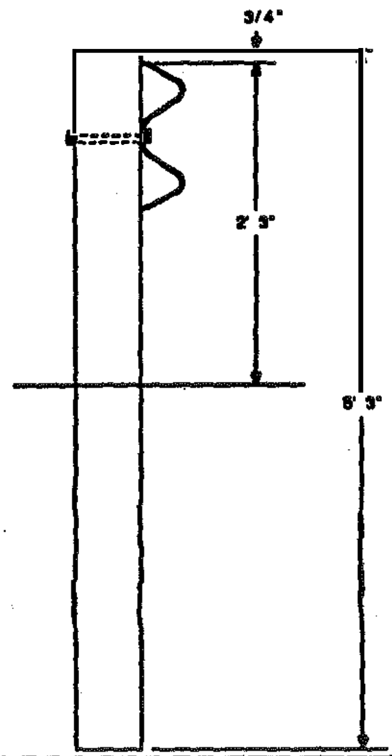



**FRACTIONAL SERVICE LEVEL**

**OPTION C (ALT)**

**(FSLC ALT)**

| | |
|---|---|
| **Beam:** | **12 ga. W-beam** |
| **Post:** | **S3 x 5.7** |
| **Post Spacing:** | **12 ft - 6 in** |
| **Bolt:** | **5/16 in dia.** |




**FRACTIONAL SERVICE LEVEL**

**OPTION D**

**(FSLD)**

| | |
|---|---|
| **Beam:** | **12 ga. W-beam** |
| **Post:** | **5 1/2 in dia. wood** |
| **Post Spacing:** | **12 ft - 6 in** |
| **Bolt:** | **5/16 in dia.** |

FRACTIONAL SERVICE LEVEL BARRIER SYSTEM CONFIGURATIONS

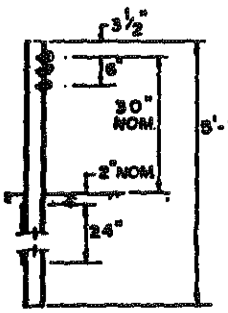
# ROADSIDE DESIGN GUIDE

Prepared by the Task Force for Roadside Safety
of the Standing Committee on Highways
Subcommittee of Design

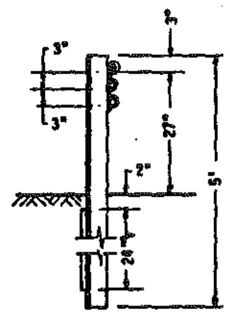
Approved as an Informational Guide
by the Executive Committee
of the
American Association of State Highway and Transportation Officials
October 1988

Published by the
American Association of State Highway and Transportation Officials
444 North Capitol Street, N.W., Suite 225
Washington, D.C. 20001

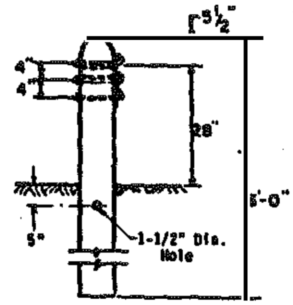
## 3-Strand Cable




G1-a




G1-b

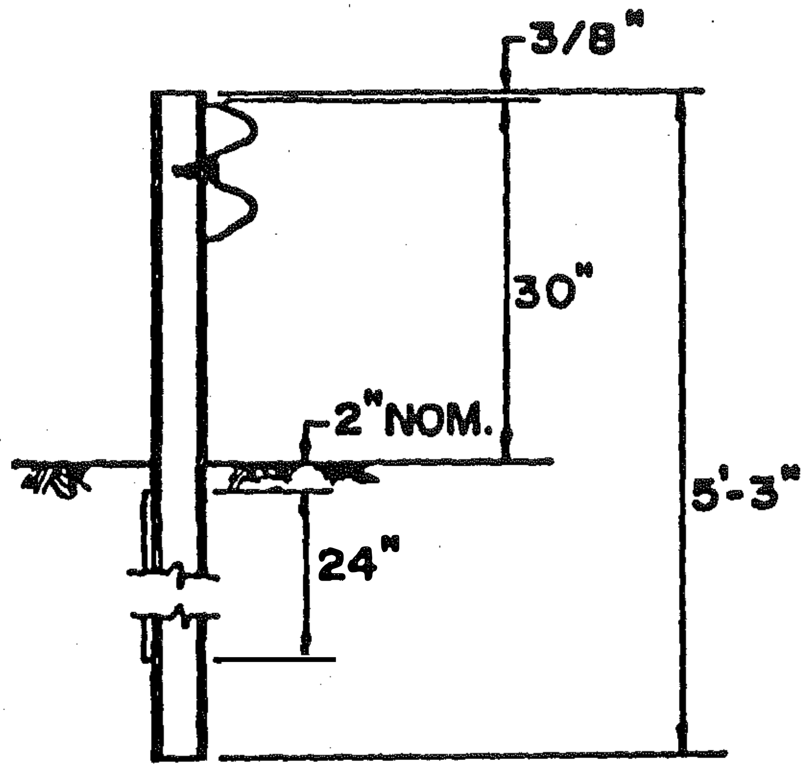



G1-c

| AASHTO Designation | G1 a | G1 b | G1 c |
|---|---|---|---|
| Post Type | S3 × 5.7 steel | 4 lb/ft steel U-channel | 5½" dia. modified wood |
| Post spacing | 16' | 16' | 12.5' |
| Beam Type | 3/4" dia steel cables | 3/4" dia steel cables | 3/4" dia steel cables |
| Nominal Barrier Height | 27–30" | 27" | 28" |
| Maximum Dynamic Deflection | 11.5' | 11.5' | 11.5' |

Remarks: For shallow angle impacts, barrier damage is usually limited to several posts, which must be replaced. Cable damage is rare except in severe crashes. A crashworthy end terminal is critical in each of the cable systems, both to provide adequate anchorage to develop full tensile strength in the cable and to minimize vehicle decelerations for impacts on either end of an installation.

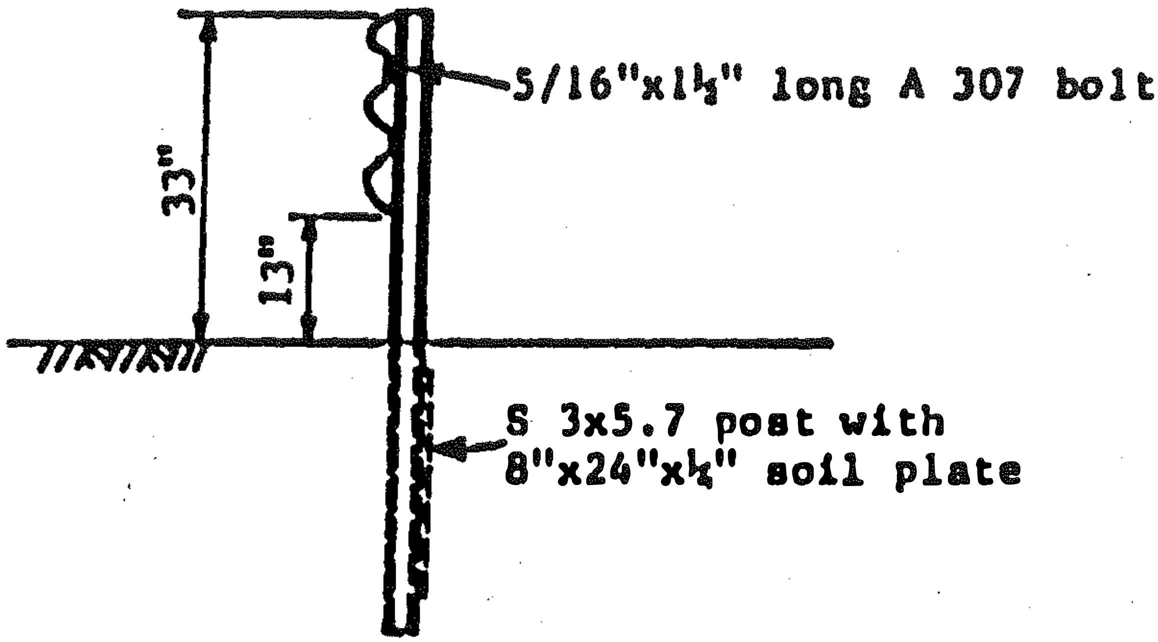
W-beam (Weak Post)




AASHTO Designation: G2

| | |
|---|---|
| Post Type | S3 × 5.7 steel |
| Post Spacing | 12′ × 6″ |
| Beam Type | 12 gauge W-section |
| Nominal Barrier Height | 30 to 33 inches. |
| Maximum Dynamic Deflection | approximately 7′ |

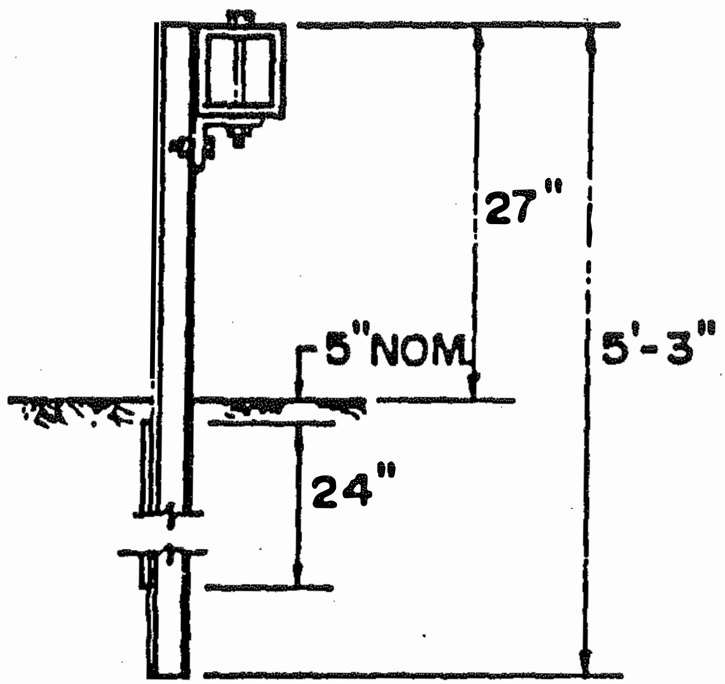
**Thrie Beam (Weak Post)**




AASHTO Designation: None

| | |
|---|---|
| Post Type | S3 × 5.7 steel. |
| Post Spacing | 12.5' |
| Beam Type | 10 Gauge Thrie-beam |
| Nominal Barrier Height | 33" |
| Maximum Dynamic Deflection | approximately 4' |

**Box Beam**




AASHTO Designation: G3

| | |
|---|---|
| Post Type | S3 × 5.7 steel |
| Post Spacing | 6' |
| Beam Type | 6" × 6" × 0.180" steel tube |
| Nominal Barrier Height | 27" |
| Maximum Dynamic Deflection | approximately 5' |

# APPENDIX D

# CRITICAL RUN-OFF-ROAD ACCIDENT RATES FOR VARYING HIGHWAY SECTION LENGTHS

TABLE D-1. CRITICAL R-O-R ACCIDENT RATES FOR RURAL ONE-LANE SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 5 | 10 |
| 100 | 1,884 | 1,272 | 896 | 602 | 469 |
| 200 | 1,272 | 896 | 659 | 468 | 379 |
| 300 | 1,031 | 745 | 561 | 412 | 341 |
| 400 | 896 | 659 | 505 | 379 | 319 |
| 500 | 808 | 602 | 468 | 357 | 304 |
| 700 | 697 | 530 | 420 | 329 | 284 |
| 1,000 | 602 | 468 | 379 | 304 | 267 |
| 1,500 | 517 | 412 | 341 | 281 | 251 |
| 2,000 | 468 | 379 | 319 | 267 | 242 |
| 2,500 | 435 | 357 | 304 | 258 | 236 |
| 3,000 | 412 | 341 | 293 | 251 | 231 |

TABLE D-2. CRITICAL R-O-R ACCIDENT RATES FOR RURAL TWO-LANE SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 5 | 10 | 20 |
| 100 | 1,470 | 954 | 645 | 411 | 307 | 239 |
| 300 | 755 | 523 | 379 | 264 | 210 | 174 |
| 500 | 574 | 411 | 307 | 222 | 182 | 155 |
| 1,000 | 411 | 307 | 239 | 182 | 155 | 137 |
| 1,500 | 344 | 264 | 210 | 165 | 144 | 129 |
| 2,000 | 307 | 239 | 194 | 155 | 137 | 124 |
| 3,000 | 264 | 210 | 174 | 144 | 129 | 119 |
| 4,000 | 239 | 194 | 163 | 137 | 124 | 115 |
| 5,000 | 222 | 182 | 155 | 132 | 121 | 113 |
| 6,000 | 210 | 174 | 150 | 129 | 119 | 111 |
| 7,000 | 201 | 168 | 146 | 126 | 117 | 110 |
| 8,000 | 194 | 163 | 142 | 124 | 115 | 109 |
| 9,000 | 188 | 159 | 139 | 122 | 114 | 108 |
| 10,000 | 182 | 155 | 137 | 121 | 113 | 107 |

TABLE D-3. CRITICAL R-O-R ACCIDENT RATES FOR RURAL THREE-LANE SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 3 | 5 |
| 100 | 1,658 | 1,097 | 758 | 622 | 496 |
| 300 | 879 | 622 | 460 | 393 | 328 |
| 500 | 679 | 496 | 378 | 328 | 281 |
| 1,000 | 496 | 378 | 300 | 267 | 235 |
| 1,500 | 421 | 328 | 267 | 241 | 215 |
| 2,000 | 378 | 300 | 248 | 225 | 203 |
| 3,000 | 328 | 267 | 225 | 208 | 190 |
| 4,000 | 300 | 248 | 212 | 197 | 182 |
| 5,000 | 281 | 235 | 203 | 190 | 176 |
| 6,000 | 267 | 225 | 197 | 185 | 172 |
| 7,000 | 256 | 218 | 192 | 181 | 169 |
| 8,000 | 248 | 212 | 188 | 177 | 167 |
| 9,000 | 241 | 208 | 185 | 175 | 165 |
| 10,000 | 235 | 203 | 182 | 172 | 163 |

TABLE D-4. CRITICAL R-O-R ACCIDENT RATES FOR RURAL FOUR-LANE DIVIDED SECTIONS (NON-INTERSTATE AND PARKWAY) SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 5 | 10 |
| 500 | 363 | 244 | 171 | 114 | 88 |
| 1,000 | 244 | 171 | 125 | 88 | 71 |
| 2,500 | 154 | 114 | 88 | 67 | 56 |
| 5,000 | 114 | 88 | 71 | 56 | 49 |
| 7,500 | 97 | 77 | 64 | 52 | 46 |
| 10,000 | 88 | 71 | 59 | 49 | 45 |
| 15,000 | 77 | 64 | 54 | 46 | 43 |
| 20,000 | 71 | 59 | 51 | 45 | 41 |
| 30,000 | 64 | 54 | 48 | 43 | 40 |
| 40,000 | 59 | 51 | 46 | 41 | 39 |
| 50,000 | 56 | 49 | 45 | 40 | 38 |

TABLE D-5. CRITICAL R-O-R ACCIDENT RATES FOR RURAL FOUR-LANE UNDIVIDED SECTIONS (FIVE-YEAR PERIOD) (1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 5 | 10 |
| 500 | 428 | 295 | 211 | 146 | 115 |
| 1,000 | 295 | 211 | 158 | 115 | 95 |
| 2,500 | 192 | 146 | 115 | 90 | 78 |
| 5,000 | 146 | 115 | 95 | 78 | 69 |
| 7,500 | 126 | 102 | 86 | 72 | 66 |
| 10,000 | 115 | 95 | 81 | 69 | 63 |
| 20,000 | 95 | 81 | 72 | 63 | 59 |
| 30,000 | 86 | 75 | 67 | 61 | 58 |
| 40,000 | 81 | 72 | 65 | 59 | 56 |
| 50,000 | 78 | 69 | 63 | 58 | 56 |

TABLE D-6. CRITICAL R-O-R ACCIDENT RATES FOR RURAL INTERSTATE SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 5 | 10 | 20 |
| 500 | 310 | 203 | 139 | 89 | 67 | 53 |
| 1,000 | 203 | 139 | 99 | 67 | 53 | 43 |
| 2,500 | 124 | 89 | 67 | 49 | 41 | 35 |
| 5,000 | 89 | 67 | 53 | 41 | 35 | 31 |
| 7,500 | 75 | 58 | 47 | 37 | 33 | 29 |
| 10,000 | 67 | 53 | 43 | 35 | 31 | 28 |
| 20,000 | 53 | 43 | 37 | 31 | 28 | 27 |
| 30,000 | 47 | 39 | 34 | 29 | 27 | 26 |
| 40,000 | 43 | 37 | 32 | 28 | 27 | 25 |
| 50,000 | 41 | 35 | 31 | 28 | 26 | 25 |

TABLE D-7. CRITICAL R-O-R ACCIDENT RATES FOR RURAL PARKWAY SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1 | 2 | 5 | 10 | 20 |
| 400 | 415 | 275 | 190 | 124 | 95 | 75 |
| 700 | 296 | 203 | 145 | 99 | 78 | 64 |
| 1,000 | 243 | 17[illegible] | 124 | 87 | 70 | 59 |
| 1,500 | 196 | 141 | 105 | 77 | 63 | 54 |
| 2,000 | 170 | 124 | 95 | 70 | 59 | 51 |
| 3,000 | 141 | 105 | 82 | 63 | 54 | 48 |
| 4,000 | 124 | 95 | 75 | 59 | 51 | 46 |
| 5,000 | 113 | 87 | 70 | 56 | 49 | 44 |
| 7,000 | 99 | 78 | 64 | 52 | 46 | 42 |
| 10,000 | 87 | 70 | 59 | 49 | 44 | 41 |
| 20,000 | 70 | 59 | 51 | 44 | 41 | 39 |
| 40,000 | 59 | 51 | 46 | 41 | 39 | 37 |

TABLE D-8. CRITICAL R-O-R ACCIDENT RATES FOR URBAN TWO-LANE SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| AADT | 0.5 | 1 | 2 | 5 | 10 |
| 500 | 533 | 377 | 279 | 200 | 163 |
| 1,000 | 377 | 279 | 215 | 163 | 137 |
| 2,500 | 256 | 200 | 163 | 131 | 116 |
| 5,000 | 200 | 163 | 137 | 116 | 105 |
| 7,500 | 176 | 147 | 127 | 109 | 101 |
| 10,000 | 163 | 137 | 120 | 105 | 98 |
| 15,000 | 147 | 127 | 113 | 101 | 95 |
| 20,000 | 137 | 120 | 108 | 98 | 93 |
| 30,000 | 127 | 113 | 103 | 95 | 91 |
| 40,000 | 120 | 108 | 100 | 93 | 89 |
| 50,000 | 116 | 105 | 98 | 92 | 88 |

TABLE D-9. CRITICAL R-O-R ACCIDENT RATES FOR URBAN THREE-LANE SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| AADT | 0.5 | 1 | 2 | 5 | 10 |
| 500 | 460 | 320 | 232 | 162 | 129 |
| 1,000 | 320 | 232 | 176 | 129 | 108 |
| 2,500 | 211 | 162 | 129 | 102 | 89 |
| 5,000 | 162 | 129 | 108 | 89 | 80 |
| 10,000 | 129 | 108 | 93 | 80 | 73 |
| 15,000 | 116 | 98 | 86 | 76 | 71 |
| 20,000 | 108 | 93 | 82 | 73 | 69 |
| 25,000 | 102 | 89 | 80 | 72 | 68 |
| 30,000 | 98 | 86 | 78 | 71 | 67 |
| 40,000 | 93 | 82 | 75 | 69 | 66 |
| 50,000 | 89 | 80 | 73 | 68 | 65 |

TABLE D-10. CRITICAL R-O-R ACCIDENT RATES FOR URBAN FOUR-LANE DIVIDED SECTIONS (NON-INTERSTATE AND PARKWAY) SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| AADT | 0.5 | 1 | 2 | 5 | 10 |
| 1,000 | 244 | 171 | 125 | 88 | 71 |
| 2,500 | 154 | 114 | 88 | 67 | 57 |
| 5,000 | 114 | 88 | 71 | 57 | 50 |
| 10,000 | 88 | 71 | 60 | 50 | 45 |
| 15,000 | 78 | 64 | 55 | 47 | 43 |
| 20,000 | 71 | 60 | 52 | 45 | 41 |
| 25,000 | 67 | 57 | 50 | 44 | 41 |
| 30,000 | 64 | 55 | 48 | 43 | 40 |
| 40,000 | 60 | 52 | 46 | 41 | 39 |
| 50,000 | 57 | 50 | 45 | 41 | 39 |
| 60,000 | 55 | 48 | 44 | 40 | 38 |

TABLE D-11. CRITICAL R-O-R ACCIDENT RATES FOR URBAN FOUR-LANE UNDIVIDED SECTIONS (FIVE-YEAR PERIOD) (1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| AADT | 0.5 | 1 | 2 | 5 | 10 |
| 1,000 | 274 | 195 | 145 | 104 | 85 |
| 2,500 | 176 | 132 | 104 | 80 | 69 |
| 5,000 | 132 | 104 | 85 | 69 | 61 |
| 10,000 | 104 | 85 | 72 | 61 | 55 |
| 15,000 | 92 | 77 | 66 | 57 | 53 |
| 20,000 | 85 | 72 | 63 | 55 | 52 |
| 25,000 | 80 | 69 | 61 | 54 | 51 |
| 30,000 | 77 | 66 | 59 | 53 | 50 |
| 40,000 | 72 | 63 | 57 | 52 | 49 |
| 50,000 | 69 | 61 | 55 | 51 | 48 |
| 60,000 | 66 | 59 | 54 | 50 | 48 |

TABLE D-12. CRITICAL R-O-R ACCIDENT RATES FOR URBAN INTERSTATE SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | |
|---|---|---|---|---|---|
| AADT | 0.5 | 1 | 2 | 5 | 10 |
| 1,000 | 250 | 175 | 129 | 91 | 74 |
| 5,000 | 118 | 91 | 74 | 59 | 52 |
| 10,000 | 91 | 74 | 62 | 52 | 47 |
| 20,000 | 74 | 62 | 54 | 47 | 43 |
| 30,000 | 66 | 57 | 50 | 45 | 42 |
| 40,000 | 62 | 54 | 48 | 43 | 41 |
| 50,000 | 59 | 52 | 47 | 42 | 40 |
| 60,000 | 57 | 50 | 46 | 42 | 40 |
| 70,000 | 55 | 49 | 45 | 41 | 39 |
| 80,000 | 54 | 48 | 44 | 41 | 39 |
| 90,000 | 53 | 47 | 44 | 40 | 39 |
| 100,000 | 52 | 47 | 43 | 40 | 39 |

TABLE D-13. CRITICAL R-O-R ACCIDENT RATES FOR URBAN PARKWAY SECTIONS (FIVE-YEAR PERIOD)(1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/100 MVM) FOR THE GIVEN SECTION LENGTH (MILES) | | | | | |
|---|---|---|---|---|---|---|
| AADT | 0.5 | 1 | 2 | 5 | 10 | 20 |
| 500 | 368 | 248 | 174 | 116 | 90 | 73 |
| 1,000 | 248 | 174 | 127 | 90 | 73 | 61 |
| 2,500 | 156 | 116 | 90 | 68 | 58 | 51 |
| 5,000 | 116 | 90 | 73 | 58 | 51 | 46 |
| 7,500 | 100 | 79 | 65 | 53 | 48 | 44 |
| 10,000 | 90 | 73 | 61 | 51 | 46 | 43 |
| 15,000 | 79 | 65 | 56 | 48 | 44 | 41 |
| 20,000 | 73 | 61 | 53 | 46 | 43 | 40 |
| 30,000 | 65 | 56 | 49 | 44 | 41 | 39 |
| 40,000 | 61 | 53 | 47 | 43 | 40 | 38 |
| 50,000 | 58 | 51 | 46 | 42 | 40 | 38 |

# APPENDIX E

# CRITICAL RUN-OFF-ROAD ACCIDENT RATES FOR 0.3-MILE HIGHWAY SECTIONS

TABLE C-1. CRITICAL R-O-R ACCIDENT RATES FOR 0.3-MILE SECTIONS ON RURAL ONE-LANE, TWO-LANE, AND THREE-LANE HIGHWAYS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/MV) BY HIGHWAY TYPE | | |
|---|---|---|---|
| | ONE-LANE | TWO-LANE | THREE-LANE |
| 100 | 7.75 | 6.23 | 6.92 |
| 500 | 3.09 | 2.26 | 2.64 |
| 1,000 | 2.23 | 1.57 | 1.87 |
| 2,500 | 1.55 | 1.03 | 1.26 |
| 5,000 | 1.23 | 0.79 | 0.99 |
| 7,500 | 1.10 | 0.69 | 0.87 |
| 10,000 | 1.02 | 0.63 | 0.80 |
| 15,000 | 0.93 | 0.56 | 0.72 |
| 20,000 | 0.88 | 0.52 | 0.68 |

TABLE 6-2. CRITICAL R-O-R ACCIDENT RATES FOR 0.3-MILE SECTIONS ON RURAL FOUR-LANE HIGHWAYS, INTERSTATES, AND PARKWAYS (FIVE-YEAR PERIOD)(1983-1987)

| AADT | CRITICAL ACCIDENT RATE (ACC/MV) BY HIGHWAY TYPE | | | |
|---|---|---|---|---|
| | FOUR-LANE UNDIVIDED | FOUR-LANE DIVIDED (NON-INTERSTATE AND PARKWAY) | INTERSTATE | PARKWAY |
| 500 | 1.74 | 1.50 | 1.31 | 1.49 |
| 1,000 | 1.16 | 0.98 | 0.83 | 0.97 |
| 2,500 | 0.72 | 0.59 | 0.49 | 0.59 |
| 5,000 | 0.53 | 0.42 | 0.34 | 0.42 |
| 10,000 | 0.41 | 0.32 | 0.25 | 0.32 |
| 15,000 | 0.36 | 0.27 | 0.21 | 0.27 |
| 20,000 | 0.33 | 0.25 | 0.19 | 0.25 |
| 30,000 | 0.29 | 0.22 | 0.16 | 0.22 |
| 40,000 | 0.27 | 0.20 | 0.15 | 0.20 |
| 50,000 | 0.26 | 0.19 | 0.14 | 0.19 |

TABLE E-3. CRITICAL R-O-R ACCIDENT RATES FOR 0.3-MILE SECTIONS ON URBAN OTHER, TWO-LANE, AND THREE-LANE HIGHWAYS (FIVE-YEAR PERIOD) (1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/MV) BY HIGHWAY TYPE | | |
|---|---|---|---|
| AADT | OTHER | TWO-LANE | THREE-LANE |
| 500 | 1.40 | 2.12 | 1.85 |
| 1,000 | 0.90 | 1.45 | 1.25 |
| 2,500 | 0.54 | 0.94 | 0.79 |
| 5,000 | 0.38 | 0.72 | 0.59 |
| 7,500 | 0.32 | 0.62 | 0.50 |
| 10,000 | 0.28 | 0.57 | 0.46 |
| 15,000 | 0.24 | 0.50 | 0.40 |
| 20,000 | 0.22 | 0.47 | 0.37 |
| 30,000 | 0.19 | 0.42 | 0.33 |
| 40,000 | 0.17 | 0.40 | 0.31 |

TABLE 5-4. CRITICAL R-O-R ACCIDENT RATES FOR 0.3-MILE SECTIONS ON URBAN FOUR-LANE HIGHWAYS, INTERSTATES, AND PARKWAYS (FIVE-YEAR PERIOD) (1983-1987)

| | CRITICAL ACCIDENT RATE (ACC/MV) BY HIGHWAY TYPE | | | |
|---|---|---|---|---|
| AADT | FOUR-LANE UNDIVIDED | FOUR-LANE DIVIDED (NON-INTERSTATE AND PARKWAY) | INTERSTATE | PARKWAY |
| 1,000 | 1.08 | 0.98 | 1.00 | 0.99 |
| 5,000 | 0.49 | 0.43 | 0.44 | 0.43 |
| 10,000 | 0.37 | 0.32 | 0.33 | 0.32 |
| 15,000 | 0.32 | 0.28 | 0.28 | 0.28 |
| 20,000 | 0.29 | 0.25 | 0.26 | 0.25 |
| 30,000 | 0.26 | 0.22 | 0.23 | 0.22 |
| 40,000 | 0.24 | 0.20 | 0.21 | 0.21 |
| 50,000 | 0.23 | 0.19 | 0.20 | 0.20 |
| 60,000 | 0.22 | 0.18 | 0.19 | 0.19 |
| 70,000 | 0.21 | 0.18 | 0.18 | 0.18 |
| 80,000 | 0.21 | 0.17 | 0.18 | 0.18 |
| 90,000 | 0.20 | 0.17 | 0.17 | 0.17 |
| 100,000 | 0.20 | 0.16 | 0.17 | 0.17 |

# APPENDIX F

# ROADSIDE IMPROVEMENT COSTS

SELECTED AVERAGE UNIT BID PRICES FOR PROJECTS AWARDED IN 1988

| ITEM DESCRIPTION | TOTAL UNIT | AMT QUAN | AVE U BID | TOTAL AMOUNT |
|---|---|---|---|---|
| Guardrail-Steel W Beam-S Face | lin ft | 1073273.26 | 8.0659 | 8656908.96 |
| Guardrail-Steel W Beam-B Face | lin ft | 5575.00 | 13.0874 | 72962.50 |
| Guardrail-Steel W Beam-S Face A | lin ft | 5037.50 | 17.7207 | 89268.00 |
| Hauling Guardrail | lin ft | 307592.00 | 0.1808 | 55606.37 |
| Guardrail Terminal Sect No 1 | each | 1345.00 | 30.5492 | 41088.65 |
| Guardrail Con to Br End Type A | each | 158.00 | 517.2468 | 81725.00 |
| Guardrail Terminal Sect No 2 | each | 3.00 | 55.0000 | 165.00 |
| Guardrail End Treatment Type 8 | each | 21.00 | 4600.0000 | 96600.00 |
| Guardrail End Treatment Type 6 | each | 34.00 | 594.7059 | 20220.00 |

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17320 W. Eight Mile Road
Southfield, MI 48075

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6300 Georgetown Pike
McLean, VA 22101

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**16. Abstract**

This guide presents information for estimating the costs and safety benefits which would be expected due to various improvements on specific sections of rural, two-lane roads. Such improvements covered in this guide include lane widening, shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvements. This guide will be useful to those involved with the design of 3R-type projects, particularly for improvement projects which will be constructed on existing vertical and horizontal alignment and within the existing right-of-way.

The accident relationships with roadway geometrics and cost data contained in this guide resulted from research conducted for the Federal Highway Administration. FHWA research report FHWA/RD-87/008 entitled "Safety Effects of Cross-Section Design for Two-Lane Roads, Volume I, Final Report" contains the major results and conclusions of the study. FHWA research report number FHWA/RD-87/009 subtitled "Volume II, Appendixes" contains details on the data base and the data analysis.

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Roadside improvement costs.

| Action | Object | Unit | Unit Costs (1985 $) | | |
|---|---|---|---|---|---|
| | | | High | Median | Low |
| Remove | Trees | Each | 550 | 200 | 70 |
| Relocate | Small sign | Each | 440 | 200 | 70 |
| Relocate | Large sign | Each | 3,000 | 1,100 | 500 |
| Remove | Small sign | Each | 220 | 40 | 15 |
| Remove | Large sign | Each | 600 | 175 | 25 |
| Relocate | Luminaire support | Each | 1,500 | 600 | 300 |
| Relocate | Mailboxes/newsboxes | Each | 300 | 120 | 60 |
| Relocate | Fire hydrant | Each | 2,200 | 1,100 | 550 |
| Remove | Fire hydrant | Each | 340 | 250 | 175 |
| Install New | Impact attenuator-foam type | Each | 26,000 | 20,000 | 10,000 |
| Install New | Impact attenuator-hydraulic type | Each | 34,000 | 28,000 | 22,000 |
| Install New | Impact attenuator-sand-filled type | Each | 6,000 | 4,000 | 3,000 |
| Clear and Grub | Trees | Acre | 8,000 | 3,500 | 1,000 |
| Relocate | Guardrail | L.F. | 19.00 | 8.00 | 6.00 |
| Remove | Guardrail | L.F. | 5.50 | 1.50 | 0.70 |
| Install New | Guardrail | L.F. | 31.00 | 10.00 | 7.60 |
| Install New | Guardrail end-anchor | Each | 800 | 500 | 350 |
| Relocate | Cable guardrail | L.F. | 5.00 | 3.50 | 2.50 |
| Remove | Cable guardrail | L.F. | 3.00 | 1.10 | 0.75 |
| Install New | Cable guardrail | L.F. | 9.00 | 6.00 | 3.20 |
| Relocate | Fence | L.F. | 10.00 | 3.00 | 1.00 |
| Remove | Fence | L.F. | 5.00 | 0.80 | 0.20 |
| Relocate | Chain-link fence | L.F. | 20.00 | 13.00 | 10.00 |
| Remove | Chain-link fence | L.F. | 6.00 | 2.75 | 1.70 |

L.F. = Linear Foot

Summary of costs for relocating utility poles.

| Type of Utility Poles or Lines | Range of Installation Costs (Dollars per Pole) | | Average Installation Cost (Dollars per Pole) | |
|---|---|---|---|---|
| | Rural | Urban | Rural | Urban |
| Wood Telephone Poles | $160-$600 | $160-$754 | $345 | $425 |
| Wood Power Poles Carrying <69 KV Lines | $150-$4,000 | $150-$4,000 | $1,270 | $1,440 |
| Non-Wood Poles (Metal, Concrete or Other) | $630-$3,250 | $630-$3,370 | $1,740 | $1,810 |
| Heavy Wood Distribution and Wood Transmission Poles | $580-$5,500 | $500-$7,100 | $2,270 | $2,940 |
| Steel Transmission Poles | $10,000-$30,000 | $20,000-$40,000 | $20,000 | $30,000 |

Based on information from 31 utility companies in 20 States throughout the U.S. (1982).

[Source: Zegeer, C.V. and Parker, M.R., "Cost-Effectiveness of Countermeasures for Utility Pole Accidents," January 1983.][6]

Estimated costs for flattening sideslopes to 4:1 (both sides of road).[2]

| Before Sideslope Condition | | Costs ($1,000/mile) | | |
|---|---|---|---|---|
| Ratio | Height of Fill (ft.)* | High | Median | Low |
| 1.5:1 | 3 | 381 | 121 | 48 |
| 2:1 | 3 | 405 | 129 | 51 |
| 2.5:1 | 2 | 390 | 131 | 52 |
| 3:1 | 2 | 405 | 136 | 54 |
| 1.5:1 | 7 | 560 | 148 | 57 |
| 2:1 | 5 | 279 | 88 | 35 |
| 3:1 | 3 | 190 | 70 | 28 |

*-Vertical distance from edge of shoulder to the original ground at the toe of the fill slope or to the bottom of ditch.

Costs of adding one foot to each lane or one foot to each shoulder (i.e., both directions).[2]

| Shoulder Type | Cost Category | 1985 Lane Widening Cost ($1,000/mile), CL | 1985 Shoulder Widening Cost ($1,000/mile), CS |
|---|---|---|---|
| Gravel | High | 58.2 | 21.8 |
| | Median | 24.8 | 8.2 |
| | Low | 13.8 | 3.6 |
| Paved | High | 61.6 | 25.0 |
| | Median | 27.8 | 11.0 |
| | Low | 16.4 | 6.4 |

Cost of slopework portion of widening project.[2]

| Total Width Added to Each Side (WL + WS) in Feet | Sideslope[1] | | 1985 Costs ($1,000/Mile), E | | |
|---|---|---|---|---|---|
| | Ratio Before Imp. | Height of Fill (ft.)[2] | High | Median | Low |
| 2 | 2:1 | 3 | 387 | 127 | 49 |
| | 4:1 | 1 | 440 | 139 | 55 |
| | 6:1 | 1 | 408 | 128 | 49 |
| | 2:1 | 5 | 303 | 91 | 37 |
| | 4:1 | 3 | 117 | 41 | 15 |
| | 6:1 | 2 | 115 | 40 | 15 |
| | 4:1 | 5 | 188 | 59 | 23 |
| | 6:1 | 3 | 88 | 35 | 14 |
| | 4:1 | 7 | 199 | 64 | 25 |
| 4 | 2:1 | 3 | 475 | 153 | 62 |
| | 4:1 | 1 | 484 | 150 | 59 |
| | 6:1 | 1 | 449 | 139 | 56 |
| | 2:1 | 5 | 346 | 103 | 41 |
| | 4:1 | 3 | 219 | 73 | 29 |
| | 6:1 | 2 | 195 | 68 | 27 |
| | 4:1 | 5 | 280 | 80 | 31 |
| | 6:1 | 3 | 108 | 40 | 15 |
| | 4:1 | 7 | 318 | 91 | 34 |
| 8 | 2:1 | 3 | 529 | 169 | 68 |
| | 4:1 | 1 | 550 | 168 | 66 |
| | 6:1 | 1 | 508 | 156 | 62 |
| | 2:1 | 5 | 414 | 121 | 49 |
| | 4:1 | 3 | 358 | 113 | 46 |
| | 6:1 | 2 | 322 | 103 | 42 |
| | 4:1 | 5 | 445 | 117 | 44 |
| | 6:1 | 3 | 244 | 72 | 26 |
| | 4:1 | 7 | 559 | 145 | 56 |

1 The procedure assumes that slope work results in sideslopes of 4:1 or flatter; simple "vee" ditches where the sideslope and backslope intersect; and backslopes of 3:1.

2 Vertical distance from edge of shoulder to the original ground at the toe of the fill slope or to the bottom of ditch.

# APPENDIX G

# ACCIDENT REDUCTION FACTORS

Research Report
UKTRP-85-6

# DEVELOPMENT OF ACCIDENT REDUCTION FACTORS

by

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and

Federal Highway Administration
US Department of Transportation



March 1985

TABLE 8. RECOMMENDED REDUCTION FACTORS FOR SAFETY IMPROVEMENTS

| | PERCENTAGE REDUCTION IN TOTAL ACCIDENTS |
|---|---|
| I. SIGNS | |
| A. WARNING SIGNS | |
| 1. Intersections | |
| a. Urban Area | 30 |
| b. Rural Area | 40 |
| 2. Sections | |
| a. Urban Area | 15 |
| b. Rural Area | 20 |
| 3. Curves | 30 |
| B. REGULATORY SIGNS | |
| 1. Intersections | 50 |
| 2. Other | 25 |
| C. GUIDANCE SIGNS | 15 |
| D. OTHER | |
| 1. Variable Message Signs | 10 |
| 2. Upgrade Signing | 15 |
| II. SIGNALS | |
| A. NEW SIGNAL INSTALLATION | 20 |
| B. SIGNAL MODERNIZATION, MODIFICATION, OR UPGRADNG | 20 |
| C. WARNING SIGNALS/FLASHING BEACONS | |
| 1. Intersections | |
| a. Red-yellow | 30 |
| b. 4-way red | 65 |
| c. Advance | 25 |
| 2. Curves | 30 |
| 3. RR Crossing | 80 |
| 4. Pedestrian Signal | 15(50P) |
| D. SIGNAL PHASING | |
| 1. Add protected left-turn phase | 25(85[1]) |
| 2. Add permissive left-turn phase | 10(40[1]) |
| 3. Improve timing | 10 |
| 4. Add pedestrian phase | 30(60P) |

TABLE 8. RECOMMENDED REDUCTION FACTORS FOR SAFETY IMPROVEMENTS (Cont.)

| | PERCENTAGE REDUCTION IN TOTAL ACCIDENTS |
|---|---|
| 5. Increase clearance internal | 30 |
| E. OTHER | |
| 1. Pretimed to actuated | 20 |
| 2. 12-inch lens | 10 |
| III. DELINEATION | |
| A. POST DELINEATORS | 20 |
| B. RAISED PAVEMENT MARKERS | $5(20^{wn})(10^{dn})$ |
| IV. PAVEMENT MARKING | |
| A. ADD CENTERLINE | 30 |
| B. ADD EDGELINE | 15 |
| C. ADD NO PASSING STRIPING | 40 |
| D. TRANSVERSE STRIPING | 15 |
| E. LANE USE/PAVEMENT ARROWS | 30 |
| V. CHANNELIZATION | |
| A. GENERAL INTERSECTION | 20 |
| B. LEFT-TURN CHANNELIZATION | |
| 1. Signalized Intersection | |
| a. Left-turn phase | 30 |
| b. No left-turn phase | 15 |
| 2. Non-Signalized Intersection | |
| a. With curb | 60 |
| b. Painted | 30 |
| C. CONTINUOUS LEFT-TURN LANE | 30 |
| VI. CONSTRUCTION/RECONSTRUCTION | |
| A. LANE ADDITION | |
| 1. Left-Turn Lane | |
| a. Without signal | 25 |
| b. With signal | 30 |
| c. Two-way left-turn lane | 30 |
| 2. Acceleration/Deceleration Lane | 10 |

TABLE 8. RECOMMENDED REDUCTION FACTORS FOR SAFETY IMPROVEMENTS (Cont.)

| | PERCENTAGE REDUCTION IN TOTAL ACCIDENTS |
|---|---|
| 3. Passing Lane | 20 |
| 4. Shoulder | 20 |
| 5. Climbing Lane | 10 |
| B. LANE/SHOULDER WIDENING | 20 |
| C. ALIGNMENT | |
| 1. Change horizontal alignment | 30 |
| 2. Change Vertical alignment | 45 |
| 3. Change horizontal and vertical alignment | 50 |
| D. CURVE RECONSTRUCTION | 50 |
| E. BRIDGES | |
| 1. Widen Bridge | 40 |
| 2. Replace Bridge | 40 |
| F. INTERSECTION/INTERCHANGE | |
| 1. Construct Interchange | 50 |
| 2. Reconstruct Intersection | 40 |
| G. OTHER | |
| 1. Improve sight distance | 30 |
| 2. Correct/improve superelevation | 40 |
| 3. Close median openings | 30 |
| 4. Increase turning radii at intersections | 15 |
| 5. Frontage road | 40 |
| 6. Ramp modification | 25 |
| 7. Flatten side slope | 15 |
| 8. Construct pedestrian crossover | 95P |
| VII. PAVEMENT TREATMENT | |
| A. RESURFACING | $20(40^{W})$ |
| B. SKID RESISTANCE | |
| 1. Deslicking | $20(40^{W})$ |
| 2. Pavement grooving | $15(55^{W})$ |
| C. RUMBLE STRIPS | 25 |

TABLE 8. RECOMMENDED REDUCTION FACTORS FOR SAFETY IMPROVEMENTS (Cont.)

| | PERCENTAGE REDUCTION IN TOTAL ACCIDENTS |
|---|---|
| VIII. SAFETY BARRIERS | |
| A. MEDIAN BARRIERS | $0(60^{f})(10^{i})$ |
| B. CRASH CUSHION | $0(75^{f})(50^{i})$ |
| C. GUARDRAIL | $0(55^{f})(35^{i})$ |
| IX. SAFETY LIGHTING | |
| A. GENERAL | $25(50^{n})$ |
| B. INTERSECTIONS | $25(55^{n})$ |
| C. SECTIONS | $25(50^{n})$ |
| D. RAILROAD CROSSINGS | $30(60^{n})$ |
| E. INTERCHANGES | $25(50^{n})$ |
| X. SAFETY POLES AND POSTS | |
| A. BREAKAWAY SIGNS | $0(60^{f})(30^{i})$ |
| B. Breakaway Utility Poles | $0(40^{f})(30^{i})$ |
| XI. RAILROAD CROSSING | |
| A. FLASHING BEACONS | $65^{t}$ |
| B. AUTOMATIC GATES | $75^{t}$ |
| C. RR PAVEMENT MARKINGS | 10 |
| XII. REMOVAL/RELOCATION OF ROADSIDE OBJECTS | |
| A. REMOVE FIXED OBJECTS | $0(50^{f})(15^{i})$ |
| B. RELOCATE FIXED OBJECTS | $0(40^{f})(15^{i})$ |
| XIII. OTHER | |
| A. FENCING | $90^{d}$ |
| B. ELIMINATE PARKING | 30 |
| C. PROHIBIT TURNING MOVEMENTS | 40 |

p - pedestrian accidents
l - left-turn accidents
wn - wet-nighttime accidents
dn - dry-nighttime accidents
w - wet pavement accidents
f - fatal accidents
i - injury accidents
n - nighttime accidents
t - train accidents
d - animal accidents

# APPENDIX H

# BUDGET OPTIMIZATION EXAMPLE

Research Report
UKTRP-83-12

# USER'S MANUAL FOR DYNAMIC PROGRAMMING FOR HIGHWAY SAFETY IMPROVEMENT PROGRAM

by

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Commonwealth of Kentucky



July 1983

Example Number 1.

EXAMPLE NUMBER ONE OF DYNAMIC PROGRAMMING (Title)
Five locations
Consider budgets of $100,000 to $500,000 by $100,000.
Cost of fatality = $190,000
Cost of non-fatal injury = 7,200
Cost of PDO accident = 1,020
Interest rate = 10 percent
Traffic growth rate = 4 percent per year

Information for Location Number One:
Location number = 0001
Location name = Exit Ramp at MP 106.3
3.5 years of accident data :
4 fatalities, 11 non-fatal injuries, 12 PDO accidents

| Three alternatives: | Improved Delineation | Clear Gore Area | Impact Attenuator |
|---|---|---|---|
| Initial Cost: | $3,000 | $7,500 | $15,000 |
| Life: | 3 years | 20 years | 20 years |
| Annual Maint. Cost: | $ 0 | $ 0 | $ 500 |
| Red. in Fatalities: | 10% | 50% | 75% |
| Red. in Injuries: | 10% | 50% | 50% |
| Red. in PDO Acc.: | 10% | 0% | -65% |

Information for Location Number Two:
Location number = 0002
Location name = Intersection at MP 153.6
3.5 years of accident data:
9 fatalities, 28 non-fatal injuries, 112 PDO accidents.

| Two alternatives: | Install Flashing Signals | Install Warning Signs |
|---|---|---|
| Initial Cost: | $15,000 | $ 1,200 |
| Life: | 20 years | 20 years |
| Annual Maint. Cost: | $ 500 | $ 0 |
| Red. in Fatalities: | 10% | 5% |
| Red. in Injuries: | 10% | 5% |
| Red. in PDO Acc.: | 10% | 5% |

Information for Location Number Three:
Location number = 0003
Location name = Curve at MP 87.9
2 years of accident data:
6 fatalities, 9 non-fatal injuries, 8 PDO accidents.

| Two alternatives: | Install Guardrail | Remove Rock Outcropping |
|---|---|---|
| Initial Cost: | $ 8,000 | $ 35,000 |
| Life: | 20 years | 20 years |
| Annual Maint. Cost: | $ 100 | $ 0 |
| Red. in Fatalities: | 15% | 75% |
| Red. in Injuries: | 15% | 50% |
| Red. in PDO Acc.: | -40% | 25% |

Information for Location Number Four:

Location number = 0004

Location name = Bridge at MP 206.1

4 years of accident data:

2 fatalities, 8 non-fatal injuries, 47 PDO accidents.

| One alternative: | Deslicking Pavement |
|---|---|
| Initial Cost: | $30,000 |
| Life: | 20 years |
| Annual Maint. Cost: | $ 0 |
| Red. in Fatalities: | 15% |
| Red. in Injuries: | 15% |
| Red. in PDO Acc.: | 15% |

Information for Location Number Five:

Location number = 0005

Location name = Narrow bridge at MP 27.1

4 years of accident data:

5 fatalities, 15 non-fatal injuries, 17 PDO accidents.

| Two alternatives: | Widen Bridge | Delineate Approach |
|---|---|---|
| Initial Cost: | $130,000 | $ 200 |
| Life: | 20 years | 5 years |
| Annual Maint. Cost: | $ 0 | $ 0 |
| Red. in Fatalities: | 50% | 5% |
| Red. in Injuries: | 50% | 5% |
| Red. in PDO Acc.: | 50% | 5% |

LOC NO

1 EXIT RAMP AT MP 106.3

ACCIDENT HISTORY 3.50 YEARS.

| FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|
| 4 | 11 | 12 |

| ALTERNATIVE | COST | LIFE | MAIN COST | EFFECT ON: FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|---|---|---|---|
| 1 | 3000. | 3 | 0. | 0.10 | 0.10 | 0.10 |
| 2 | 7500. | 20 | 0. | 0.50 | 0.50 | 0.0 |
| 3 | 15000. | 20 | 500. | 0.75 | 0.50 | -0.65 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---------------- NOT DISCOUNTED ----------------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 0.0 | 3000.00 | 72980.38 | 24.33 |
| 2 | 0.0 | 7500.00 | 2397714.00 | 319.70 |
| 3 | 10000.00 | 15000.00 | 3427965.00 | 228.53 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 0.0 | 3000.00 | 65304.54 | 21.77 |
| 2 | 0.0 | 7500.00 | 1401220.00 | 186.83 |
| 3 | 4256.77 | 15000.00 | 2004885.00 | 133.66 |

LOC NO
2 INTERSECTION AT MP 153.6

ACCIDENT HISTORY 3.50 YEARS.

| FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|
| 9 | 28 | 112 |

| ALTERNATIVE | COST | LIFE | MAIN COST | EFFECT ON: FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|---|---|---|---|
| 1 | 15000. | 20 | 500. | 0.10 | 0.10 | 0.10 |
| 2 | 1200. | 20 | 0. | 0.05 | 0.05 | 0.05 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---------------- NOT DISCOUNTED ----------------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 10000.00 | 15000.00 | 1147621.00 | 76.51 |
| 2 | 0.0 | 1200.00 | 578810.25 | 482.34 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 4256.77 | 15000.00 | 672255.50 | 44.82 |
| 2 | 0.0 | 1200.00 | 338256.00 | 281.88 |

LOC NO
3 CURVE AT MP 87.9

ACCIDENT HISTORY 2.00 YEARS.

| FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|
| 6 | 9 | 8 |

| ALTERNATIVE | COST | LIFE | MAIN COST | EFFECT ON: FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|---|---|---|---|
| 1 | 8000. | 20 | 100. | 0.15 | 0.15 | -0.40 |
| 2 | 35000. | 20 | 0. | 0.75 | 0.50 | 0.25 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---------------- NOT DISCOUNTED ----------------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 2000.00 | 8000.00 | 1772558.00 | 221.57 |
| 2 | 0.0 | 35000.00 | 8894400.00 | 254.13 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 851.35 | 8000.00 | 1036198.19 | 129.52 |
| 2 | 0.0 | 35000.00 | 5197876.00 | 148.51 |

LOC NO

4 BRIDGE AT MP 206.1

ACCIDENT HISTORY 4.00 YEARS.

| FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|
| 2 | 8 | 47 |

| ALTERNATIVE | COST | LIFE | MAIN COST | EFFECT ON: FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|---|---|---|---|
| 1 | 30000. | 20 | 0. | 0.15 | 0.15 | 0.15 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---------------- NOT DISCOUNTED ----------------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 0.0 | 30000.00 | 364154.25 | 12.14 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 0.0 | 30000.00 | 212811.25 | 7.09 |

LOC NO

5 NARROW BRIDGE AT MP 27.1

ACCIDENT HISTORY 4.00 YEARS.

| FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|
| 5 | 15 | 17 |

| ALTERNATIVE | COST | LIFE | MAIN COST | EFFECT ON: FATALITIES | NON-FATAL INJURIES | PDO ACCIDENTS |
|---|---|---|---|---|---|---|
| 1 | 130000. | 20 | 0. | 0.50 | 0.50 | 0.50 |
| 2 | 200. | 5 | 0. | 0.05 | 0.05 | 0.05 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------------- NOT DISCOUNTED ---------------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 0.0 | 130000.00 | 2688350.00 | 20.68 |
| 2 | 0.0 | 200.00 | 67208.69 | 336.04 |

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

| ALTERNATIVE | MAINTENANCE | COST | BENEFIT | BENEFIT/COST |
|---|---|---|---|---|
| 1 | 0.0 | 130000.00 | 1571068.00 | 12.09 |
| 2 | 0.0 | 200.00 | 56978.82 | 284.89 |

*************************PARAMETER VALUES*************************

-----------------OUTPUT-----------------

| LOCATIONS | BUDGET MINIMUM | BUDGET MAXIMUM | BUDGET INCREMENT |
|---|---|---|---|
| 5 | 100000.00 | 500000.00 | 100000.00 |

| LOCATION | ALTERNATIVES |
|---|---|
| 1 | 3 |
| 2 | 2 |
| 3 | 2 |
| 4 | 1 |
| 5 | 2 |

******************************LOCATIONS,ALTERNATIVES,COSTS AND BENEFITS******************************

BENEFITS (MAINTENANCE INCLUDED) DISCOUNTED BACK TO PRESENT WORTH

| LOCATION | LOCATION NAME | ALT-NUM | COST | BENEFIT | B/C RATIO |
|---|---|---|---|---|---|
| 1 | EXIT RAMP AT MP 106.3 | 1 | 3000. | 65305. | 21.77 |
| 1 | EXIT RAMP AT MP 106.3 | 2 | 7500. | 1401220. | 186.83 |
| 1 | EXIT RAMP AT MP 106.3 | 3 | 15000. | 2004885. | 133.66 |
| 2 | INTERSECTION AT MP 153.6 | 1 | 15000. | 672256. | 44.82 |
| 2 | INTERSECTION AT MP 153.6 | 2 | 1200. | 338256. | 281.88 |
| 3 | CURVE AT MP 87.9 | 1 | 8000. | 1036198. | 129.52 |
| 3 | CURVE AT MP 87.9 | 2 | 35000. | 5197876. | 148.51 |
| 4 | BRIDGE AT MP 206.1 | 1 | 30000. | 212811. | 7.09 |
| 5 | NARROW BRIDGE AT MP 27.1 | 1 | 130000. | 1571068. | 12.09 |
| 5 | NARROW BRIDGE AT MP 27.1 | 2 | 200. | 56979. | 284.89 |

************LOCATIONS,ALTERNATIVES,COSTS, AND BENEFITS-ORDERED BY BENEFIT/COST RATIO**************

BENEFITS (MAINTENANCE INCLUDED) DISCOUNTED BACK TO PRESENT WORTH

| LOCATION | LOCATION NAME | ALT-NUM | COST | BENEFIT | B/C RATIO |
|---|---|---|---|---|---|
| 5 | NARROW BRIDGE AT MP 27.1 | 2 | 200. | 56979. | 284.89 |
| 2 | INTERSECTION AT MP 153.6 | 2 | 1200. | 338256. | 281.88 |
| 1 | EXIT RAMP AT MP 106.3 | 2 | 7500. | 1401220. | 186.83 |
| 3 | CURVE AT MP 87.9 | 2 | 35000. | 5197876. | 148.51 |
| 1 | EXIT RAMP AT MP 106.3 | 3 | 15000. | 2004885. | 133.66 |
| 3 | CURVE AT MP 87.9 | 1 | 8000. | 1036198. | 129.52 |
| 2 | INTERSECTION AT MP 153.6 | 1 | 15000. | 672256. | 44.82 |
| 1 | EXIT RAMP AT MP 106.3 | 1 | 3000. | 65305. | 21.77 |
| 5 | NARROW BRIDGE AT MP 27.1 | 1 | 130000. | 1571068. | 12.09 |
| 4 | BRIDGE AT MP 206.1 | 1 | 30000. | 212811. | 7.09 |

OPTIMUM PROJECT SELECTIONS FOR BUDGET = 100000.

| LOCATION | LOCATION NAME | ALT-NUM | COST | BENEFIT | ACCUM BENEFIT |
|---|---|---|---|---|---|
| 1 | EXIT RAMP AT MP 106.3 | 3 | 15000. | 2004885. | 2004885. |
| 2 | INTERSECTION AT MP 153.6 | 1 | 15000. | 672256. | 2677140. |
| 3 | CURVE AT MP 87.9 | 2 | 35000. | 5197876. | 7875016. |
| 4 | BRIDGE AT MP 206.1 | 1 | 30000. | 212811. | 8087827. |
| 5 | NARROW BRIDGE AT MP 27.1 | 2 | 200. | 56979. | 8144805. |
| ***************************** TOTALS ***************************** | | | 95200. | 8144805. | 8144805. |

STING OF SELECTED PROJECTS BY B/C RATIO FOR BUDGET = 100000.

| .OCATION | LOCATION NAME | ALT-NUM | COST | BENEFIT | ACCUM BENEFIT | B/C | ACCUM B/C |
|---|---|---|---|---|---|---|---|
| 5 | NARROW BRIDGE AT MP 27.1 | 2 | 200. | 56979. | 56979. | 284.89 | 284.89 |
| 3 | CURVE AT MP 87.9 | 2 | 35000. | 5197876. | 5254854. | 148.51 | 149.29 |
| 1 | EXIT RAMP AT MP 106.3 | 3 | 15000. | 2004885. | 7259739. | 133.66 | 144.62 |
| 2 | INTERSECTION AT MP 153.6 | 1 | 15000. | 672256. | 7931994. | 44.82 | 121.66 |
| 4 | BRIDGE AT MP 206.1 | 1 | 30000. | 212811. | 8144805. | 7.09 | 85.55 |
| ************************** TOTALS ****************************** | | | 95200. | 8144805. | 8144805. | | 85.55 |