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Low-Service-Level Guardrail Systems

An NCHRP digest of the findings from the final report on NCHRP Project 22-5A, "Warrants for the Installation of Low-Service-Level Guardrail Systems," conducted by Wilbur Smith Associates, Mr. Louis B. Stephens, Principal Investigator.

INTRODUCTION

Most operational guardrail systems in the United States have been developed to contain a 4,500-lb vehicle impacting at 60 mph and 25 deg. The use of design criteria based on these test conditions has resulted in relatively expensive guardrail installations. For low-volume roads, there is a need to determine the conditions under which less stringent guardrail requirements are warranted in order to avoid excessive expenditures and provide adequate safety performance. NCHRP Project 22-5A was initiated to address this need.

The final report on NCHRP Project 22-5A, "Low-Service-Level Guardrail Systems," documents the development and evaluation of five low-service-level barriers systems. Full-scale crash testing has shown that these systems contained a 3,400-lb vehicle impacting at 50 mph and 20 deg, and thus can be used to improve the level of safety on low-service-level roads. (However, correlating crash test conditions with field situations should be considered.) In addition, a user's guide was prepared to provide design details for the developed systems and to outline specific warrants for their placement on low-volume roads.

The research involved establishing preliminary designs for low-volume guardrail systems using the least expensive existing hardware and design details. These designs were then evaluated using BARRIER VII computer simulation program (*1*) to determine the severity level, in terms of vehicle weight, impact speed, and impact angle, at which each system performed adequately. Adequate performance was defined as the ability of the guardrail system to redirect the vehicle within lateral deflections approximating those of current AASHTO operational barrier systems and without structural failure of the barrier. The weight, speed, and angle obtained for the limiting simulations provided an upper bound for the low-volume performance standards. The preliminary guardrail designs were then reevaluated and modified to develop new, but less expensive, designs that could meet these performance standards. The final guardrail systems were then developed based on the results of computer simulations, component testing, and full-scale crash tests. Also, the research identified the conditions at which low-service-level barriers are likely to be used, provided estimates of likely barrier costs, and outlined the steps of warranting procedures to help justify the use of these barriers.

Information furnished by several state highway agencies that use cable and weak-post W-beam guardrail; several guardrail contractors and suppliers; and other sources was used to estimate the installation, repair, and maintenance costs of various guardrail systems currently in use. Hardware detail drawings for the low-service-level barriers were produced in a style consistent with that identified in the AASHTO-AGC-ARTBA Joint Cooperative Committee Report, *A Guide to Standardized Highway Barrier Rail Hardware* (*2*). The warranting procedure provided a systematic method for identifying and classifying roadside hazards, and analyzing alternative treatments.

This digest provides a description of the developed low-service-level barrier systems, test results, and the warranting procedure. The material in this digest is extracted from the final report on this project.

FINDINGS

Barrier Systems

The primary components of a barrier system are the post, rail, and terminal (or end treatment). In identifying potential low-service-level barrier systems, use of existing components was favored over fabricated or new components because information on material costs was readily available and experience with their behavior was easily obtainable.

An objective of this research was to design at least two fractional-service-level barrier systems that would perform appropriately at lower impact severities than those required for existing systems and thus would be suitable for use on low-volume roads. To avoid the extensive design and validation testing required for new systems, consideration was given to modifying existing systems and using existing terminals. Design and evaluation of these fractional-service-level systems were accomplished by evaluating the individual components and the complete system, and limited testing at reduced severity levels.

Several types of posts were considered from which the S3x5.7 steel post, the 4 lb/ft steel post, and the 5½-in.-diameter wood post were selected for use in the barrier systems. Also, several rails were considered from which the two ¾-in. cables and the W-beam rail were selected for use in the barrier systems. Existing terminals were considered and the modified Texas Twist and the New York terminals were selected for the W-beam and cable systems, respectively.

The possible W-beam configurations were W-beam on 5½-in. wood posts, W-beam on S3x5.7 steel posts, and W-beam on 4 lb/ft steel posts; all of which included the modified Texas Twist terminal. Although a 16-ft post spacing proved adequate for the 5½-in. wood and S3x5.7 steel posts when simulated with BARRIER VII computer program, the standard 12½-ft spacing was adopted. As connections and splices cannot be analyzed by BARRIER VII computer program, it was recognized that a splice in the span between posts might snag and tear at impact or that the beam material might tear at the bolts exists.

Alternative cable system configurations were the 5½-in.-diameter wood post with two cables, the standard S3x5.7 steel post with two cables, and the 4 lb/ft steel post with two cables. Because of the promising behavior of the 4 lb/ft steel posts with the G1 system, this system was adopted with the stipulation that if the system proved to be too flexible, the S3x5.7 posts would replace the 4 lb/ft posts. Simulation of the two-cable system with BARRIER VII computer program indicated that deflections for 12½- and 16-ft post spacings were well within the limits stipulated for standard conditions.

Four systems were initially selected for evaluation in this program. These were the W-beam with 4 lb/ft steel posts or 5½-in.-diameter wood posts at 12½-ft spacing and the two ¾-in.-diameter cable rail with 4 lb/ft steel posts or 5½-in.-diameter wood posts at 16 ft spacing. In addition, an alternative system utilizing S3x5.7 steel posts was selected. These systems were designated GL1 through GL5 and their details are illustrated in Figure 1.

Because low-volume roadways are characterized by lower design speeds, smaller vehicles, and narrower right of ways than principal arterials, the test conditions described in *NCHRP Report 230,* "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances" (*3*) are considered excessive. A previous study (*4*) has shown that 98 percent of all accidents on two-lane rural roads occurred at a speed of 50 mph or less and that 47 percent of all vehicles and 74 percent of the passenger cars have curb weights of 3,400 lbs or less. Based on these values, the structural adequacy of barriers on low-volume roads was evaluated by crash tests with a 3,400-lb sedan impacting at 50 mph and a 20-deg impact angle, and occupant risk was evaluated by impact tests of an 1,800-lb sedan impacting at 50 mph and a 20-deg impact angle. Test conditions and evaluation criteria are summarized in Tables 1 and 2, respectively.

Crash Test Evaluations

Eight full-scale crash tests were performed on four guardrail systems using a 3,400-lb sedan impacting at 50 mph. Two tests were conducted at 0-deg, 0-ft offset impacts into the guardrail terminals, and the other tests were conducted at 20-deg impacts into the guardrail length of need. An unrestrained side impact dummy was placed in the front seat on the impact side of the vehicle. Impact data were recorded from transducers mounted in the dummy and on the vehicle. Extensive film coverage also documented the barrier, vehicle, and dummy behaviors. The tests were conducted and reported in accordance with the procedures described in *NCHRP Report 230* (*3*) and evaluated using the criteria listed in Tables 1 and 2. Test results indicated that the five guardrail systems, GL1 through GL5, met the recommended acceptance criteria. However, the GL1 system exhibited an uncontrolled post failure mode that was considered hazardous to other vehicles and, therefore, it was judged as unacceptable.

Cost Evaluation

For evaluating the economic feasibility of low-service-level barriers, installation, collision repair, and routine maintenance costs must be considered. Data were collected on material costs for the conventional W-beam strong post, 3-strand cable, and W-beam weak post systems to help estimate the cost of the new systems. Also, eight state highway agencies known to use flexible barrier systems, 16 firms known to supply guardrail materials or to install guardrails, and other sources supplied information on installation. Based on this information, estimates were developed for the installation costs of guardrail systems and end treatments. In addition, based on the limited repair-cost data provided in FHWA report, "Value Engineering Study of Guardrail and Impact Attenuator Repair" (*4*), and other considerations, estimates were developed for guardrail/collision repair, assuming that collisions were severe enough to require repairs. Consequently, if property-damage-only accidents are considered not severe enough to warrant guardrail repair and a severity index of 2.5 for the guardrail is assumed, only 43 percent of the collisions with guardrail will be severe enough to require repair.

Although data are not available on the average length-of-cable-system repairs, crash test results and field experience suggest that collisions with cable systems would result in more damage than would be expected for W-beam systems, thus a cable damage length twice that for the W-beam system has been assumed.

As limited data are available on collision repair costs of end treatments, the assumptions were made that the full end treatment must be replaced when repair is necessary, and that 50 percent of the collisions will result in repair. Estimated average repair costs for the different end treatments were used for the analysis performed by ROADSIDE computer program (*5*).

A review of several maintenance management systems revealed that routine maintenance of guardrail is not a reported activity, although guardrail repair is frequently reported. It appears that maintenance is performed when collision repair is required, otherwise it is deferred until guardrail replacement is necessary. Based on these findings, routine maintenance was not considered in the analysis.

Development of Warrants

Because of the variety of possible conditions on low-volume roads, a framework for evaluating hazards and treatment alternatives was developed with provisions to accommodate local conditions, policies, and resources. This framework can be used with or without the ROADSIDE computer program, as described in the *Roadside Design Guide* (*5*), to evaluate possible treatment alternatives for assumed hazards and select an appropriate and cost-effective treatment.

The first step in the process, as illustrated in Figure 2, is to identify and assess the severity of hazards. Hazards that are obviously less severe than likely treatments should be left untreated. A classification of the physical attributes of the hazard is necessary to evaluate treatment alternatives. Finally, information on accident history, if available, will be considered in this evaluation.

The framework allows the consideration of all possible treatment alternatives, including the following:

- Change clear zone,
- Remove or relocate the hazard,
- Change the hazard,
- Shield the hazard, or
- Accept the risk.

Shielding the hazard includes consideration of the low-service-level barriers developed in this research as well as commonly used conventional barriers. Other systems, such as concrete barriers and crash cushions, could also be evaluated, although their high cost would make their use impractical for most low-volume road applications. Risk acceptance is considered a possible alternative because other actions may not be cost-effective and the funds available to highway agencies limited.

The framework for evaluating alternatives is illustrated in Figure 3. Local conditions, policies, and resources are considered in each of the analysis steps. The final step in this process is to rank the alternatives into three groups according to priority: (1) those obviously cost-effective (preferred); (2) those that may be cost-effective (secondary); and (3) those that are obviously not cost-effective (drop).

For guardrail alternatives, these groupings were arrived at by performing a series of economic analyses using the ROADSIDE computer program for typical low-volume road conditions. Procedures were developed for area hazards, for point hazards, and for bridge approaches. Assumptions were made for most of the inputs that allowed the analysis to be reduced to the following variables:

- Dimensions of the hazard;
- Location of the hazard;
- Severity index of the hazard;
- Guardrail system; and
- Average Daily Traffic (ADT).

Although reasonable assumptions can be made about most low-volume road conditions, it should be recognized that the analysis is very sensitive to two variables: encroachment rate and accident costs.

In addition to the encroachment model provided in the ROADSIDE system, other models which are not based on significant field data in the 0 to 2,000 ADT range were found in the literature (*6, 7, 8, 9*). Likely encroachments on horizontal curves and downgrades can be accounted for by adjusting the ADT by the factors recommended in the AASHTO *Roadside Design Guide* (*5*). Figure 4 illustrates the substantial difference in the encroachment rates estimated from the different models.

The cost of accidents, particularly fatalities, has a large impact on the economic analysis results. These costs are an estimation of the public's willingness to pay to avoid an accident. The range of accident costs reported by different sources (*10, 11*) must be adjusted to reflect the incidents per accident found for low-volume roads.

To address the uncertainty of encroachment and accident costs, the following observations are made:

1. If average conditions are used with the highest encroachment rates (*9*) and the relatively high accident costs (*10*), all guardrail alternatives that are not cost-effective are unlikely to be cost-effective under any condition.
2. Similarly, for the lowest encroachment rate based on the ROADSIDE default and the least accident costs, virtually no guardrail alternatives would be identified as cost-effective for the low ADT ranges. Therefore, the lowest encroachment rate provided by the ROADSIDE default was used along with the high accident costs (*10*) to identify those alternatives found to be cost-effective, judged as suitable, and treated as the highest priority group.
3. Alternatives falling between these two extremes are judged as possibly suitable; they could be cost-effective for certain encroachment rates and accident costs, and are regarded as the second priority group.

The suitability of low-service-level and commonly used guardrail systems was evaluated, and the results were presented in a series of charts. Based on this evaluation, guardrail systems were judged as suitable, possibly suitable, or not suitable based on dimensions, location, and severity of hazard, as well as ADT.

The ROADSIDE computer program can be used to evaluate both the preferred and secondary alternatives and identify the one with the lowest total cost. Although this method would allow the consideration of many important site-specific factors—such as speed, lane width, grade, curvature, construction costs and actual layout of the alternatives—assumptions must be made regarding encroachment rates and accident costs.

Recognizing the fact that many users will not have or desire to use ROADSIDE, the following approach is recommended:

1. From the preferred list, find the lowest cost alternative and all those that are within 120 percent of the lowest cost.
2. Select the low-cost alternative with the lowest severity index.
3. If there are no preferred alternatives, repeat steps 1 and 2 with the secondary list.
4. If there are neither preferred nor secondary alternatives, the best alternative is to accept the risk of the hazard untreated.

Steps 1 and 2 will usually yield similar results to those obtained from ROADSIDE analysis. A key consideration is the suggested treatment of the risk acceptance alternative. If there is a clear, multiyear history of no accidents and the possibility of future accidents appears unlikely, then the risk acceptance alternative is put on the preferred list. Because this option carries a zero cost, it will always be the preferred alternative in this case. If the accident history is unclear or unknown, the risk acceptance alternative is placed on the secondary list (possibly suitable). This option will always be selected unless a clearly cost-effective alternative (preferred list) can be identified. Finally, if there is a clear accident history, the risk acceptance alternative is dropped and a corrective treatment must be selected. The expected result of these recommendations are that corrective treatments (guardrail) will only be placed where highly cost-effective corrective treatments are available or where a clearly established accident history has been found. A summary of these results is illustrated in Table 3.

There are countless roadside hazards within the clear zone on low-volume roads. This procedure for analysis and evaluation of alternatives can be used to identify those locations where the greatest benefits can be derived from the available resources.

CONCLUSIONS

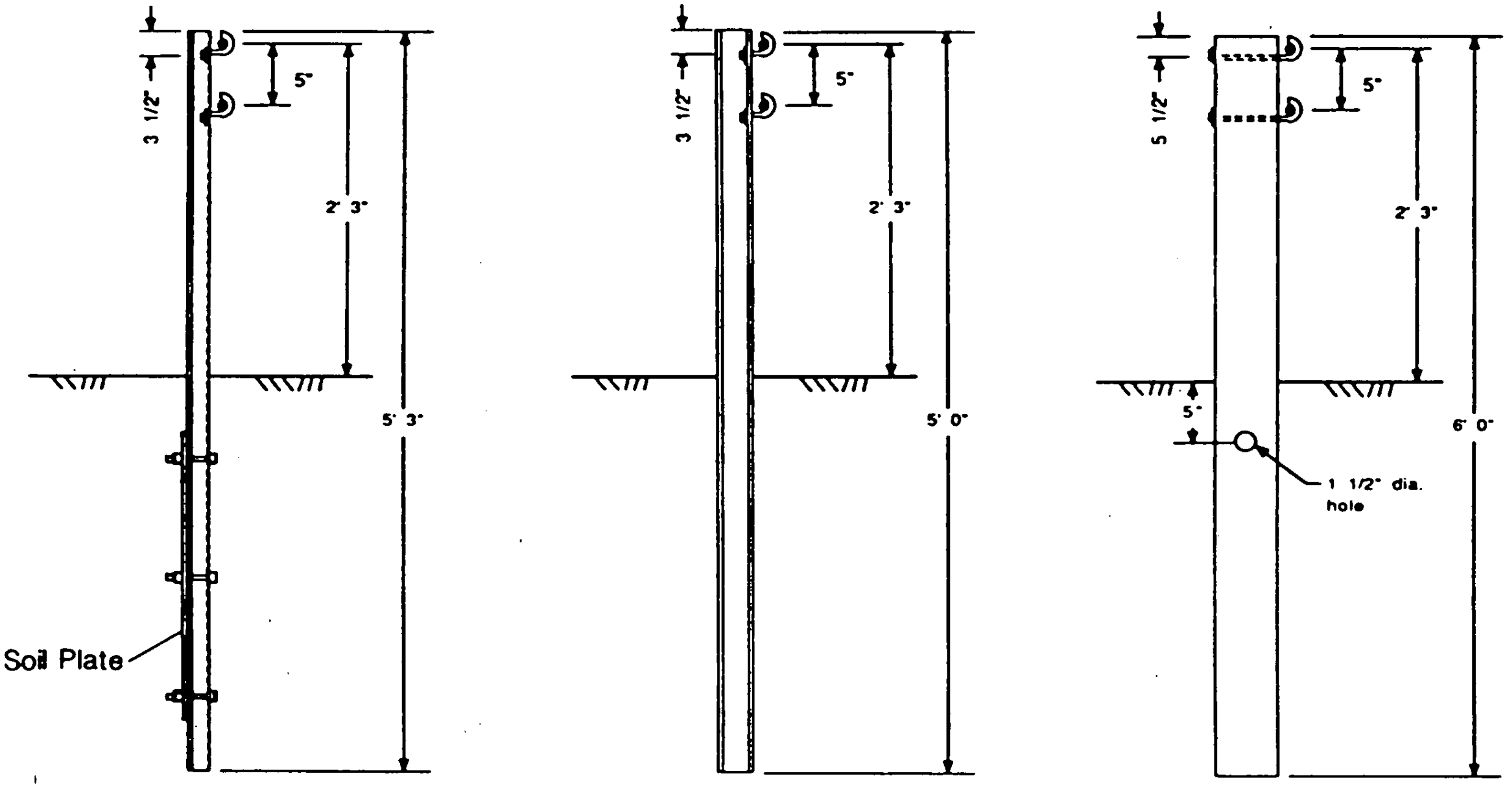
It is estimated that there are approximately 2 million miles of roads in the United States that are likely candidates for low-service-level guardrail placement. An excess of 1 million accidents occur on these roads annually, resulting in 13,000 deaths and 600,000 injuries.

Approximately 40 percent of the 1 million accidents involve run-off-the-road incidents. Proper guardrail installation could significantly lessen the severity of many of these accidents. The hardware development and warrants identified in this research, should provide valuable assistance to low-volume road engineers, who have had little or no other guidelines available specific to their needs.

Although low-volume roads are not heavily traveled, the magnitude of their inventory represents a significant accumulation of both agency and user costs. Agency expenditures are needed for maintenance, rehabilitation, safety and capacity improvements, and new construction. Although agencies are frequently unable to cope with even routine maintenance, incurred costs (including travel time, vehicle operating expenses, and losses due to accidents) can be quite high for the average user. Thus, there is a clear need for low-cost measures to reduce user costs on low-volume roads. This can be accomplished by lowering the acceptance criteria for guardrail to obtain reduced costs on low-volume roads.

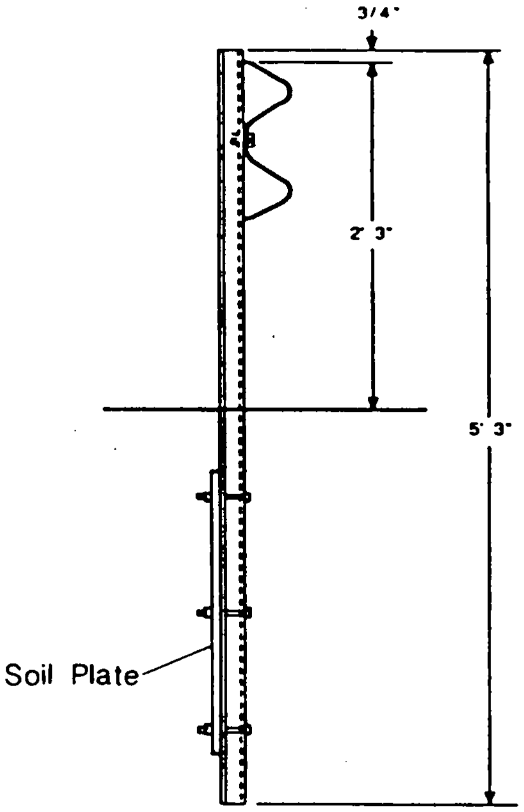
Four low-service-level guardrail systems, designated GL2 through GL5, were developed to contain a 3,400-lb vehicle impacting at 50 mph and 20 deg. A fifth system, designated GL1, also met the recommended criteria for low-service-level guardrail systems, but was judged as unacceptable because it exhibited an uncontrolled post failure mode in crash tests that was considered hazardous to other vehicles. These systems were found to be less expensive than conventional guardrail systems.

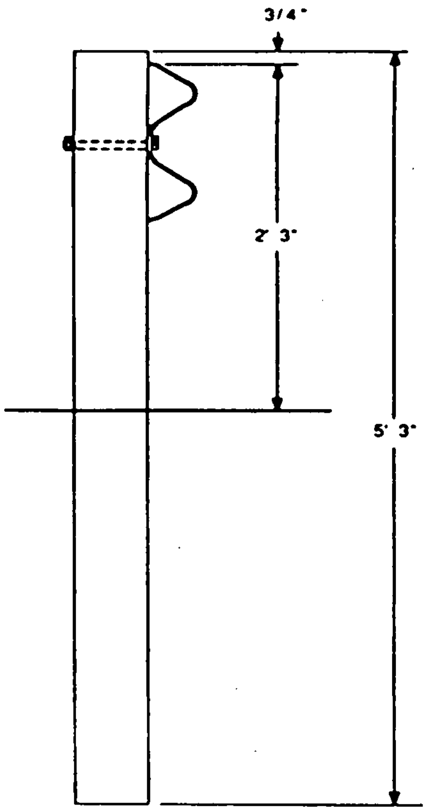
The warranting process developed in this research will assist low-volume road practitioners to determine if hazards exist, to evaluate alternatives and, if guardrail is appropriate, to select the most cost-effective system. Relatively small point hazards will justify guardrail only under relatively severe conditions close to the roadway, with ADTs generally in excess of 500. Area hazards are more likely to justify guardrail if they are of moderate-to-high severity. The procedures will find some bridge rail approaches not to be cost-effective at very low ADTs.



	GL1 System	GL2 System	GL3 System
Post Type	4 lb/ft steel section	S3XS7 steel	5 1/2-in. diameter wood
Post Spacing	16 ft	16 ft	16 ft
Beam Type	two, 3/4-in. dia cables	two, 3/4-in. dia cables	two, 3/4-in. dia cables
Barrier Height	27 in.	27 in.	27 in.
Max. Dyn. Deflection	7 ft	7 ft	7 ft

Figure 1. Details of Recommended Guardrail Systems GL1, GL2, GL3, GL4, and GL5 (Figure continues on opposite page)





	GL4 System	**GL5 System**
Post Type	4 lb/ft steel section	5-1/2 in. diameter wood
Post Spacing	12.5 ft	12.5 ft
Beam Type	12 gauge W-beam	12 gauge W-beam
Barrier Height	27 in.	27 in.
Max. Dyn. Deflection	6 ft	3 ft

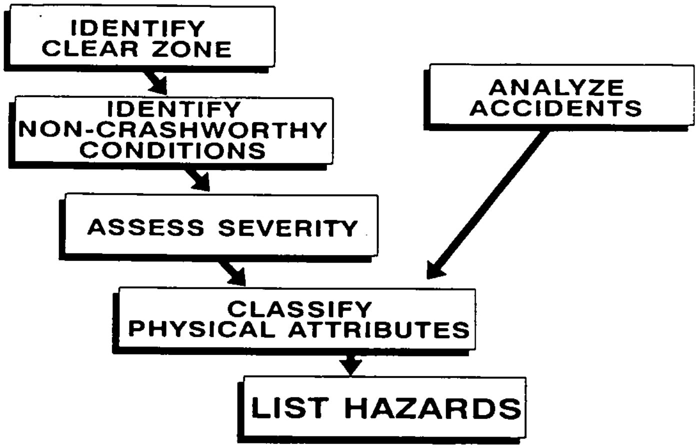


Figure 2. Hazard Identification

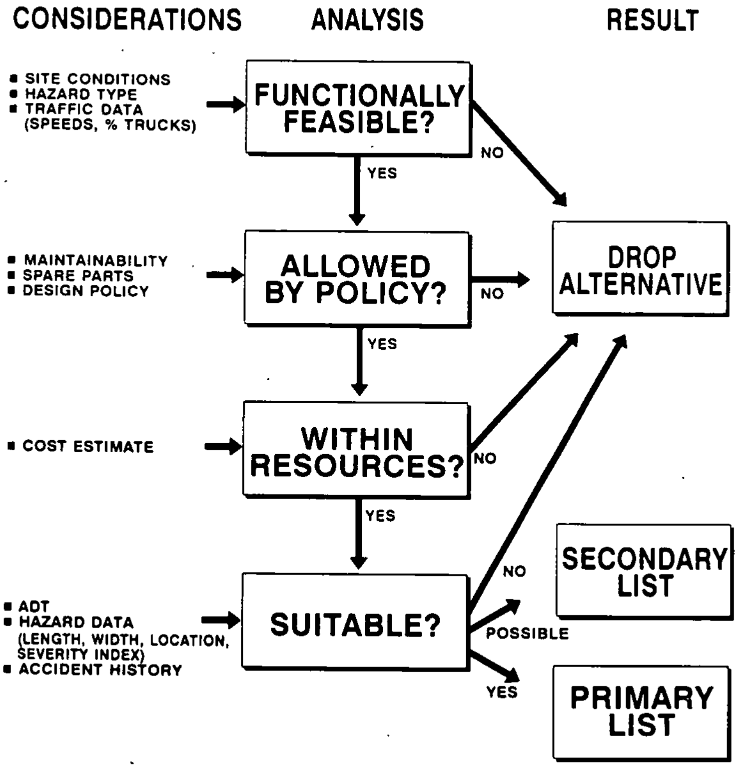


Figure 3. Approach for Evaluating Alternatives

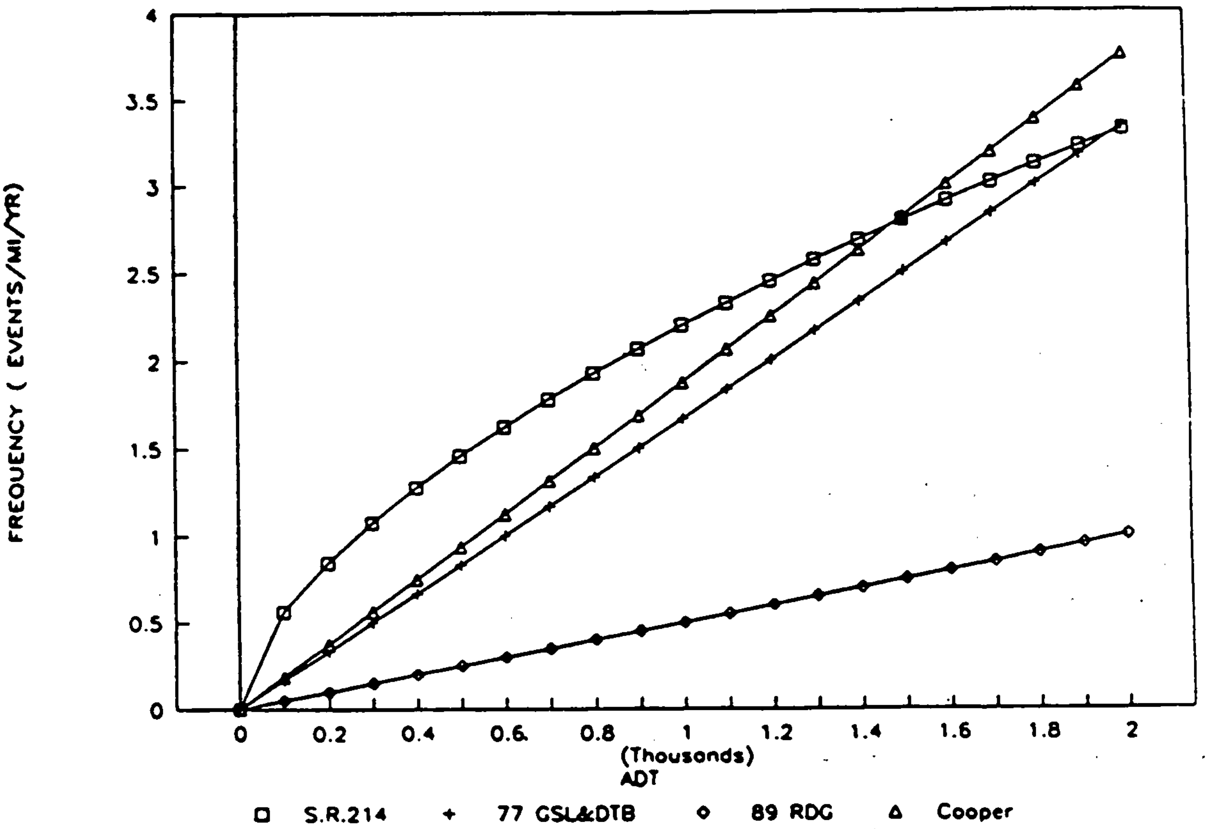


Figure 4. Encroachment Frequency Curves

TABLE 1. Recommended Crash Test Conditions

Appurtenance	Vehicle Weight (lbs.)	Impact Speed (mph)	Impact Angle[e] (deg)	Target Impact Severity [f] (ft-kips)	Impact Point [g]	Evaluation Criteria [h]
Longitudinal Barrier Length-of-Need	3400	50	20[i]	33 +7,-0	For post and beam systems, midway between posts in span containing railing splice.	A,C,D,F,G
	1800	50	20[i]	17 +4,-0	For Post and beam system, vehicle should contact railing splice.	A,C,D,E,F,G
Transition	3400	50	20[i]	33 +7,-0	15 ft upstream from second system.	A,C,D,F,G
Terminal	3400	50	20[i]	33 +7,-0	At beginning of length-of-need.	A,C,D,F,G
	3400	50	0[i]	283 +56,-0	Center nose of device.	B,C,D,E,F,H
	1800	50	20[i]	17 +4,-0	Midway btn nose and length-of-need.	B,C,D,E,F,G,H
	1800	50	0[i]	150 +30,-0	Offset 1.25 ft from center nose of device.	B,C,D,E,F,G,H

(e) +/- 2 degrees

(f) $IS = 1/2m (v \sin r)^2$ where m is vehicle test inertial mass, slugs; v is impact speed, fps; and r is impact angle for redirectional impacts or 90 deg for frontal impacts, deg.

(g) Point on appurtenance where initial vehicle contact is made.

(h) See Table 2 for performance evaluation factors.

(i) From centerline of highway.

TABLE 2. Safety Evaluation Criteria

EVALUATION FACTORS	EVALUATION CRITERIA
Structural Adequacy	A. Test article shall smoothly redirect the vehicle: the vehicle shall not penetrate or go over the installation although controlled lateral deflection of test article is accepted.
	B. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.
	C. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
Occupant Risk	D. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.
	E. Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. (0.61 m) forward and 12 in. (0.30 m) lateral displacements, shall be less than: Occupant Impact Velocity - fps Longitudinal: 40/1.33 = 30.1; Lateral: 30/1.5 + 20.0 and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations - g's Longitudinal: 20/1.33 = 15.0; Lateral: 20/1.33 = 15.0
Vehicle Trajectory	F. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.
	G. In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.
	H. Vehicle trajectory behind the test article is acceptable.

TABLE 3. Evaluation of Risk Acceptance Alternatives

Accident Experience	Accident Potential		
	High	Medium	Low
Clear History of Accidents	Not Suitable	Not Suitable	Possibly Suitable
Unclear History or Unknown	Not Suitable	Possibly Suitable	Possibly Suitable
Clear History of No Accidents	Possible Suitable	Possibly Suitable	Suitable

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