IDENTIFICATION, ANALYSIS, AND REMEDIAL
TREATMENT OF LOW GUARDRAIL IN VIRGINIA

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Guardrails that are too low may fail to safely redirect errant vehicles; instead, the vehicles may vault the guardrails, resulting in severe accidents. An analysis of data on a small sample of guardrails throughout Virginia showed that over 80% of the guardrails were lower than the current standard height of 27 in.

The causes of low guardrail were identified as installation at old standards that were lower than current standards, faulty installation, and inadequate maintenance. Methods for locating low guardrails were identified and six remedial treatments were developed ranging from removal of the guardrail to complete re-installation.

A numerical scoring system was developed whereby correction of low guardrails may be prioritized according to the degree of hazard presented by the low guardrail. The scoring system employs an equation based on the guardrail performance variables considered to be most important; namely, guardrail height, vehicle speed, and expected number of encroachments. Additional factors that can affect the degree of hazard but were not included in the equation are guardrail type, consequences of vaulting, and soil type. Provisions were made for increasing total scores for situations in which these variables are important.

SUMMARY OF FINDINGS

1. While many variables affect the performance of guardrails, one of the most significant is the height of the guardrail.

2. Low guardrail allows vehicle vaulting, particularly at high speeds and high impact angles.

3. Vehicle vaulting contributes to the severity of accidents.

4. An analysis of the data collected showed that 82.6% of the guardrail points sampled had substandard heights; 33.3% were 3 in. or more below the standard.

5. Low guardrails occur on all road classifications, but the lowest found were GR-1 on primary highways. The least number of significantly low guardrails was found on interstate roads.

6. Many existing guardrails were installed under a previous height standard lower than that currently in effect.

7. Poor installation procedures, lack of tolerance in the height specification, and insufficient inspection and quality control may cause faulty installation.

8. Inadequate maintenance may allow guardrails to become low over time, even if they were initially installed at the proper height.

CONCLUSIONS

1. Because of insufficient highway funds, it is not practical to identify and correct all low guardrails in Virginia. Furthermore, no conclusive evidence could be found to show that guardrails that are only a couple of inches low present excessive hazard to most vehicles.

2. Methods of identifying low guardrail situations and a prioritization system for correcting the most critical sitaations are needed that will be compatible with existing highway programs and work schedules. The identification methods and the prioritization system presented herein meet this requirement.

3. The prioritization system presented in this report, while not rigorously tested, includes the major variables necessary to assess the degree of hazard presented by low guardrails.

4. When applied to typical field and operational conditions, the system appears to work reasonably well in identifying low guardrail situations that are in most need of attention.

RECOMMENDATIONS

1. The Virginia Department of Highways and Transportation should experiment with the low guardrail identification methods and the prioritization system presented in this report to determine their effectiveness. Modifications may be made as necessary if indicated by experience.

2. The removal of the low guardrail should be the first remedial treatment to be considered since guardrails themselves are hazards.

3. Shoulder scraping is a simple, relatively inexpensive means of increasing the effective height of guardrails that are only a few inches low.

4. Although it appears that the lowest guardrails must be corrected by reinstallation, other corrective methods may be more desirable if experience shows them to be effective and less costly.

5. Tests should be conducted and the results monitored to determine the effectiveness of the following corrective methods.

    a. Pulling existing guardrail posts to required height.

    b. When upgrading GR-1 to GR-2, pulling existing posts to required height prior to installing additional, intermediate posts.

    c. Using extended block-outs to raise the height of the rail.

6. Damaged guardrail should be replaced in kind, unless the entire section warrants upgrading.

7. The Department should ensure that its inspectors are aware of current standards for guardrail installation. The importance of complying with the standards should be impressed upon both inspectors and contractors.

8. The Department should establish explicit inspection procedures and criteria to ensure that guardrail installations are checked properly and that they conform to the most recent safety and design standards.

9. New developments in guardrail design and applications should be followed closely so that they can be quickly assessed. For example, the Department should continue to assess the merits of thrie-beam guardrail. When standards do change, they should be disseminated promptly and accurately in Department publications.

10. The Department should investigate the feasibility of establishing a 1-in. tolerance on the height of the guardrail specifications.

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PROBLEM STATEMENT

Guardrails are designed to prevent errant vehicles from encountering roadside hazards such as steep embankments, bridge pillars, and sign supports, and to safety redirect errant vehicles in such a way as to minimize the possibility that they will interfere with other traffic. These functions are performed by two seemingly contradictory properties of the guardrail. It must be structurally adequate to withstand impacts from a wide range of vehicle sizes and weights, but it must also be able to absorb or redirect vehicle kinetic energies in such a way as to minimize horizontal accelerations.

In 44% of all fatal accidents in 1977, collision with a roadside obstacle was the first harmful event (Viner 1980). With such a large percentage of accidents involving roadside obstacles, it is essential that guardrails perform properly without presenting undue hazards themselves.

While numerous factors determine how well guardrail performs, guardrail height is one of the most critical, because of the tendency of vehicles to roll over or vault the guardrail when it is below the vehicle's center of gravity. When the height of the guardrail is substantially below the vehicle's center of gravity, vehicle vaulting is almost guaranteed, even under moderate crash conditions. In these cases, the guardrail obviously fails to perform its intended function and the result is increased accident severity (AASHTO 1977; King 1980).

That problems have resulted from the installation of low guardrail in Virginia has been acknowledged in a number of accident reports made by the Virginia Department of Transportation Safety (1976-79) crash investigation team which cited low guardrail as a factor contributing to the severity of accidents. In addition, recent changes in the Virginia Department of Highways and Transportation standard for guardrail height has raised concern among highway officials over the abundance of old and low guardrail. Since low guardrails in Virginia may be a threat to human life and safety, it was desirable to determine the extent of the problem with low guardrails and to develop methods remedying installations that are too low to perform effectively.

OBJECTIVES AND SCOPE

The objectives of this project were as follows:

1. Determine the extent of the low guardrail problem in Virginia.

2. Identify and analyze causal factors associated with low guardrail.

3. Propose remedial treatments and criteria for their application.

In Virginia, the corrugated metal beam (W-beam) type of guardrail is most common, and was, therefore, the focus of this study.

STUDY PROCEDURES

In order to achieve the stated objectives, a number of tasks were performed. A description and the purpose of each task follow.

1. Data Collection and Analysis — Data on guardrail heights and site conditions were collected using a random stratified sampling procedure. In addition to guardrail height, information was collected on location, roadway geometry, traffic characteristics, and features of the surrounding area. The data were analyzed to gain an indication of both the magnitude of the low guardrail problem in Virginia and the reasons for installing low guardrail or for the guardrail becoming low.

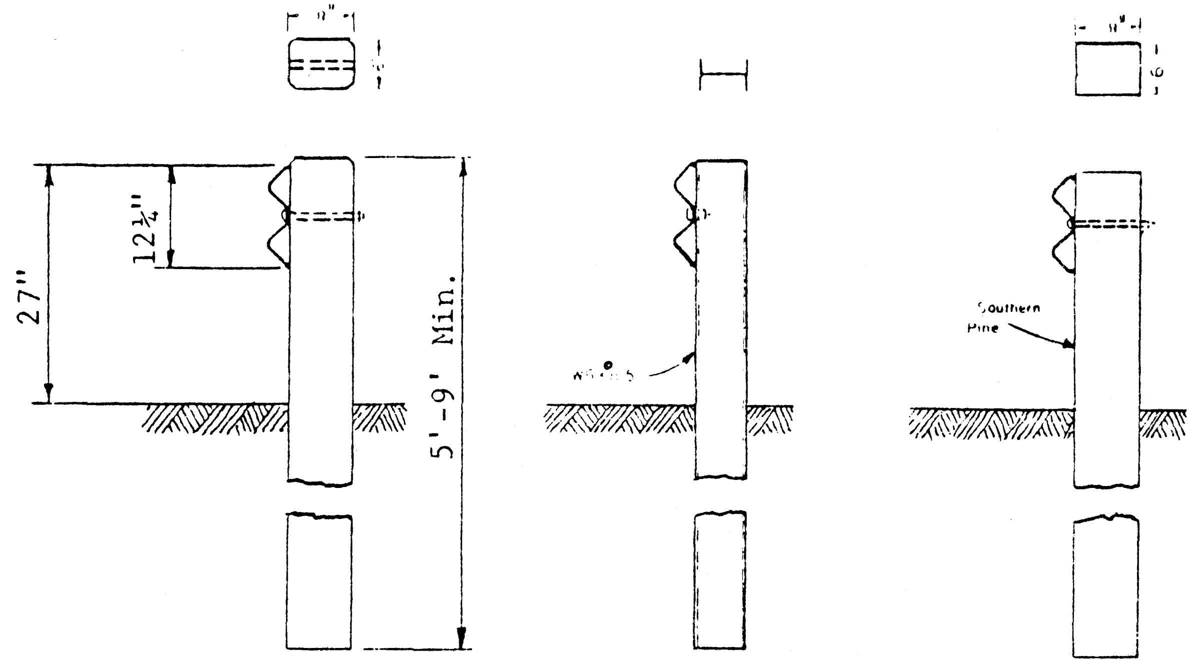
2. Identification and Analysis of Remedial Treatments — On the basis of the results of the data analysis and information gained in discussions with personnel of the Virginia Department of Highways and Transportation, six remedial treatments were developed for possible use in correcting low guardrail situations.

3. Development of Techniques for Identifying and Analyzing Low Guardrail — Because the Department of Highways and Transportation, like many other state departments of transportation, is operating on limited finances, a comprehensive program to locate and replace low guardrail is impractical. Therefore, methods of identifying the locations of low guardrails were designed that would fit into existing Department work schedules and procedures. Furthermore, a means of scheduling the replacement or modification of the most critical installations of low guardrail was developed.

TYPES OF GUARDRAIL USED IN VIRGINIA

The Virginia Department of Highways and Transportation uses two basic configurations of W-beam guardrail, the GR-1 and the GR-2 as shown in Figure 1. Both guardrail configurations use 12-gauge galvanized steel W-beam and may have concrete, strong steel, or wood posts. The type of post used is typically left up to the contractor. GR-1 is not blocked out, has a top-of-rail height of 7 in. and has a post spacing of 12.5 ft. GR-2 is blocked out, has a top-of-rail height of 27 in., and has a post spacing of 6.25 ft. The length of the post is a minimum of 5.75 ft. The Department's criteria (1979) specify that GR-1 guardrails are to be used only on state funded projects where design speeds are less than 60 mph and average daily traffic volumes are less than 750 vehicles. GR-2 guardrails are to be used on all federal aid projects and on all projects with design speeds of 60 mph or greater or average daily traffic volumes of 750 vehicles or greater. For both guard-rail types, terminal treatments must be such that vehicles will not be impaled on the ends of the guardrails. This means that the ends must either be turned down and buried or be capable of collapsing in such a way as to preclude vehicle impalement.

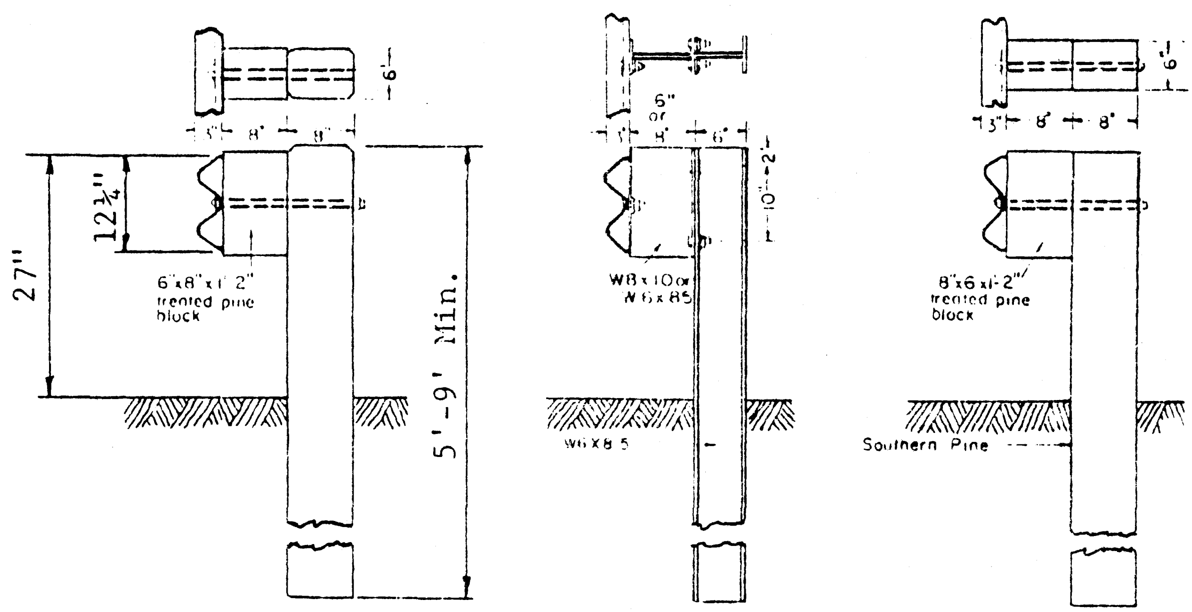
The height standards used for guardrail in Virginia from 1953 to the present are given in Table 1.



GR-1A Concrete Post

GR-1B Steel Post

GR-1C Wood Post



GR-2A Concrete Post

GR-2B Steel Post

GR-2C Wood Post

Figure 1. GR-1 and GR-2 standard W-beam guardrails.

Table 1

History of Guardrail Height Standard in Virginia

Guardrail Type	Date	Height, In.	Comments
GR-1	1953	25 (Approx.)	Standard specified a minimum rail width of 12 in. so height did not have to be exactly 25 in. Concrete post.
	1966	25¼	Rail width specified as 12¼ in. Three types of posts allowed (concrete, steel, wood).
	1975 to Present	27	Standard gives bottom-of-rail height as 14 in., top of rail height as 27 in., rail is 12¼ in. wide; this leaves discrepancy of 3/4 in.
GR-2	1953	25 (Approx.)	Minimum rail width 12 in. Steel post. At this time GR-1 and GR-2 differed only in post type.
	1966	30	GR-2 with block-outs introduced this year. Six-inch wide rub rail with height of 15 in. Three types of post allowed (concrete, steel, wood).
	1968 to Present	27	Rub rail eliminated.

DATA COLLECTION AND ANALYSIS

Date were collected at a number of locations throughout the state to determine the extent of the problem with low guardrail in Virginia. The analysis of the data was also expected to show why guardrail in Virginia is low and to indicate possible ways of remedying installations that are too low to perform effectively. The sections below give the data collection procedures, the analysis techniques, and the significant findings.

Collection

Procedure

A stratified random sampling procedure was used that included a range of roadway types, roadway configurations, guardrail types, and geographic areas. Sites were selected on a random basis and were categorized by roadway classification, i.e., as interstate, primary, or secondary. The selected sites are shown in Table 2. At each site, data were collected at three or four points along the guardrail to produce a total of 69 data points. The measurements and field notes were supplemented with photographs at each site.

The data base for this study was relatively small for two reasons. First, an analysis of early data showed that guardrails were consistently low. Therefore, emphasis was shifted from extensive data collection to the determination of the causes of guardrail being low and to development of means of correction. Second, there are only a few companies that install guardrail in Virginia and installation procedures are consistent throughout the state.

Table 2

Location of Sites

Route	County/City	Type of Guardrail
Primary		
18	Allegheny	GR-1B
20	Albemarle	GR-2B
29	Greene	GR-1B
35	Sussex	GR-2B
58	Suffolk	GR-2A
159	Allegheny	GR-1B
199	James City	GR-2C
220	Bath	GR-1B
340	Augusta	GR-2B
Secondary		
602	Albemarle	GR-1B
612	James City	GR-1C
616	Albemarle	GR-1B
637	Albemarle	GR-1B
687	Allegheny	GR-1B
708	Albemarle	GR-1B
799	Fluvanna	GR-2B
Interstate		
64	Allegheny	GR-1B
64	Goochland	GR-2B
64	Chesapeake	GR-2B
81	Rockbridge	GR-2B
95	Colonial Heights	GR-2B

Data Collected

Several types of data were collected at each site and recorded on the forms shown in the Appendix. In addition to height measurements, data included descriptions of the site, the guardrail, the pavement, the shoulder, the roadway geometry, and the traffic characteristics.

The descriptions included location of the site and salient features of the surrounding area. The location data included route number and classification, milepost number, county, district, and distance between the guardrail and the edge of pavement. Features of the surrounding areas included terrain and the roadside hazard shielded by the guardrail.

The guardrail description consisted of the type, its height, and its condition. Guardrail type was specified by post type, post spacing, and block-outs. The height was measured from the ground to the back side of the top of the rail. The condition included whether the rails or posts were damaged or deteriorated.

Pavement and shoulder descriptions consisted of type, width, condition, cross slope, and evidence of recent overlays. Types of pavement were asphalt, concrete, and surface treatment, while shoulder types were pavement, dirt, and grass. Pavement width measurements were taken as the width of the traffic lane adjacent to the guardrail. The shoulder width was measured from the edge of pavement to the face of the guardrail. The condition of the pavement included such features as potholes and cracks, while shoulder condition included such items as smoothness and evidence of soil or vegetation buildup. Roadway cross slope was described in general terms only, as no measurements were taken.

The vertical and horizontal alignments of the sites were also described in general terms, (e.g., slight curve to left, or moderate upgrade). Finally, characteristics of the traffic included the speed limit and general information on vehicle types and volumes.

Analysis

The data were analyzed with three objectives in mind. These were (1) to determine the magnitude of the low guardrail problem; (2) to determine whether significant differences existed between roadway types and between blocked out and non-blocked out guardrail, and (3) to determine the reasons for the low guardrail. Several procedures were used to analyze the data. Height frequency histograms were used to show the distribution of the data and the number of low guardrail installations. The means and standard deviations of the guardrail height were calculated for each road classification and guardrail type. The Statistical Package for the Social Sciences (Nie et al. 1970) was used to perform a t-test for differences between the means. Finally, the data sheets for each site were studied to determine the apparent reasons for the guardrail being low.

Results

The height frequency histogram shown in Figure 2 shows three peaks. Even though information on installation dates was unavailable, it is intuitively apparent that the right-most peak (i.e., 26.0 to 26.5 in.) represents guardrail that was installed under the current 27-in. height standard. Likewise, the peak between 24 and 25 in. represents guardrail that was installed under the earlier standard of 25 in. The left-most peak, between 21.0 and 21.5 in., represents sites where soil and vegetation buildup around the guardrail was evident. One of the data points in this grouping represented a damaged guardrail section. The data thus contain two main subgroups that can be related to height standards, one grouped around the most recent standard of 27 in. and the other grouped around the old standard of 25 in. In Figure 2, the peaks are slightly skewed to the right; that is, most of the data points fall to the left of the peaks. This phenomenon can be attributed to the lowest common denominator (LCD) method of installation in which adjustments to achieve uniformity in the height of the rail are always made downward. The histogram also shows that a majority of the extremely low guardrails are type GR-1 on primary highways. The lowest guardrail was found to be 9 in. below the current standard of 27 in., while the highest was only 1 in. above the standard.

The statistics in Table 3 show only small differences in the means of the data subgroups. In fact, the t-test showed the only significant difference to be between the mean heights of guardrails on interstates versus primary roadways ($t = 2.15$, $a = 0.037$). In addition, the standard deviations showed guardrail heights on interstates to be more narrowly distributed than those on other types of roads. These differences may be attributable to a higher level of control in making the installations, more uniform shoulders, and newer installations typically found on interstate highways. While the same sort of difference between means was expected between interstates and secondaries, it was not round because the sample contained several recent installations on secondaries.

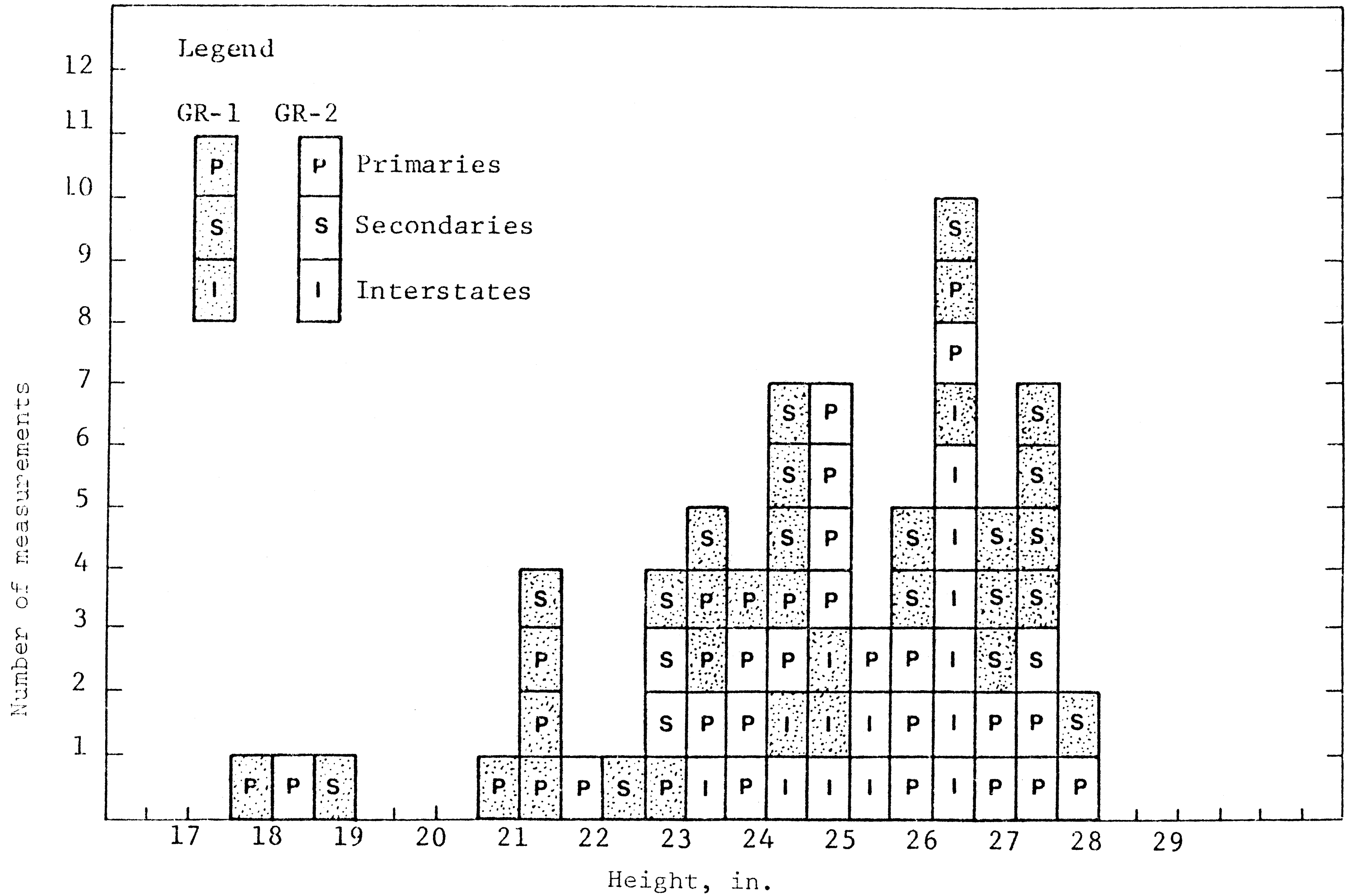


Figure 2. Height frequency histogram.

Table 3

Summary Statistics

Classification	Sample Size	Mean, in.	Standard Deviation
All	69	24.717	2.247
Interstates	15	25.483	1.015
Primaries	32	24.086	2.414
Secondaries	22	25.114	2.424
GR-1	34	24.338	2.555
GR-2	35	25.086	1.865

The cumulative frequency plots in Figures 3 and 4 demonstrate the magnitude of the low guardrail problem. Of the guardrails in the sample, 82.6% were below the current standard height of 27 in. Since the AASHTO (1977) guidelines state that correction is warranted when the deviation in the height exceeds 3 in., guardrails that are low by only a small amount are not considered to be a serious problem. By this criterion, 33.3% of the guardrails in the sample are in need of correction. Figures 3 and 4 show that the largest problems are with GR-1 guardrails (41.2% are 3 in. or more below standard) and with guardrails on primaries (46.9% are 3 in. or more below standard). Interstates have the fewest number of seriously low guardrails (6.7% are 3 in. or more below standard). It should be noted, however, that all of the guardrails sampled on interstates were below the 27 in. standard height.

An analysis of the available data, a review of guardrail standards, and discussions with Virginia Department of Highways and Transportation personnel showed that low guardrail can be attributed to three main causes. First, a large number of guardrails still in service were installed under the old standards. Second, installation procedures (namely the LCD method) along with insufficient inspection and quality control, cause guardrail to be installed too low. Third, inadequate maintenance allows guardrail to become low over time, even if it was installed at the proper height. No evidence could be found to suggest that old guardrail installations had settled as a result of poor soil conditions or vibration caused by traffic.

Guardrail standards change over the years as new and better information shows that old standards are inadequate. As new standards become effective, a large proportion of existing guardrails become substandard due to the impracticality and cost of a major upgrading program. Because installation dates were not available for most of the guardrails in the sample, it was difficult to determine which standard was applicable at the time of installation.

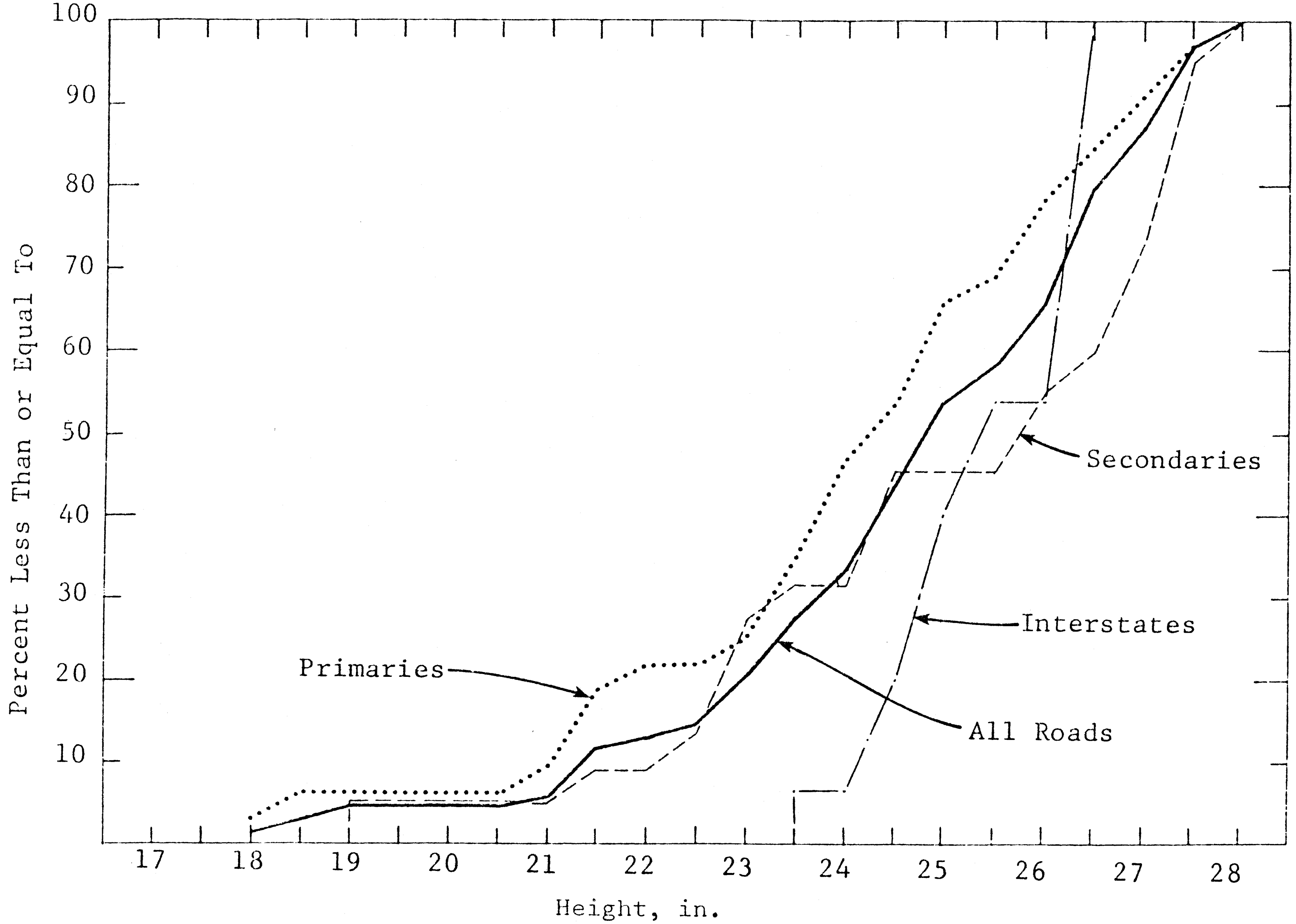


Figure 3. Cumulative frequency curves by roadway classification.

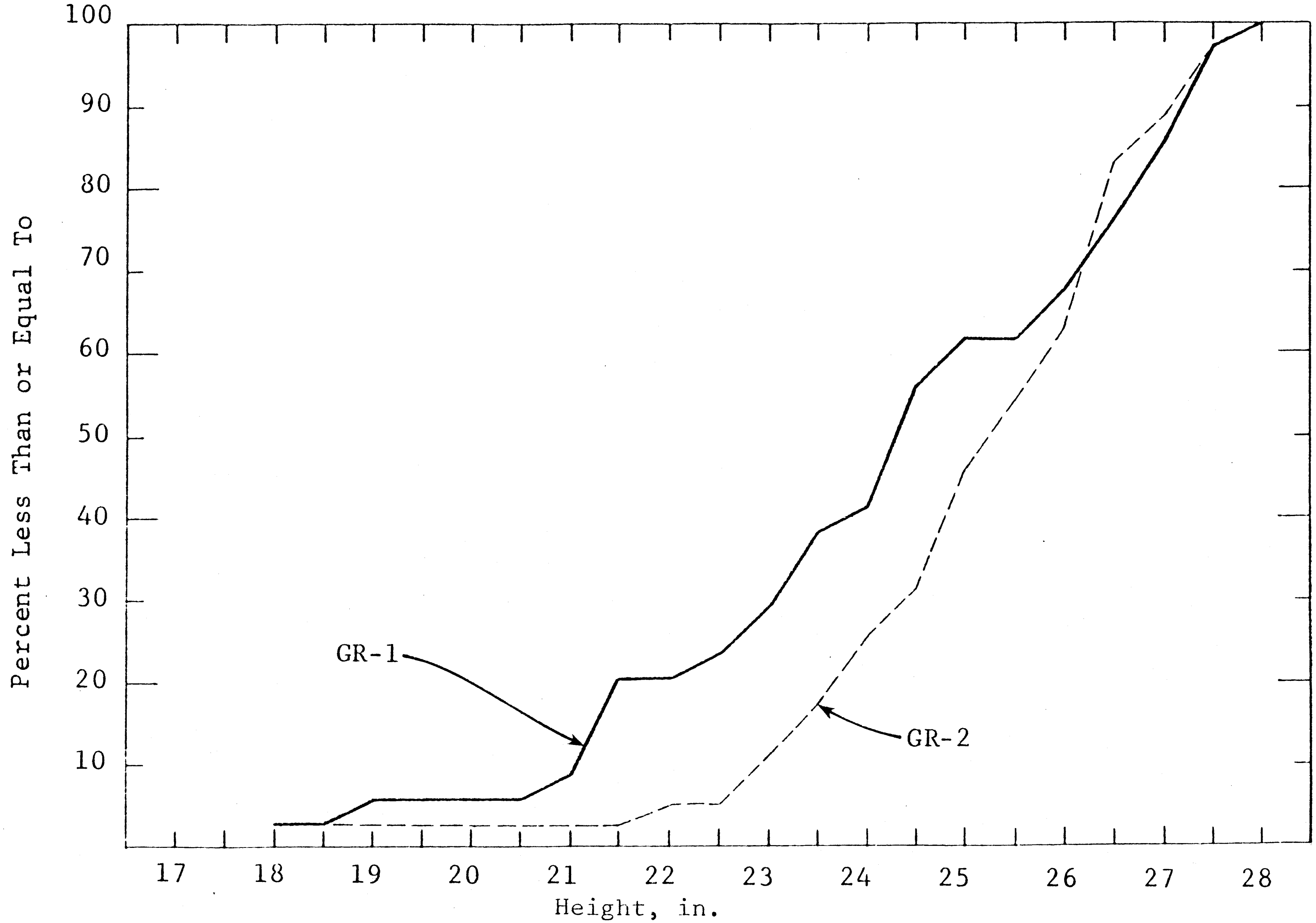


Figure 4. Cumulative frequency curves by guardrail type.

It did appear, however, that much of the low guardrail in the sample was installed at the old standard. In addition, those guardrails installed more recently did conform more closely to the current standard. Since upgrading of the height standard for GR-1 was more recent than for GR-2, a greater percentage of GR-1 was lower than 27 in.

Guardrail installation procedures contributed to a large degree to the low guardrail problem, primarily because of the LCD method of installation. This problem stems from the fact that it is impossible to obtain a uniform guardrail installation because of the incompatibility of rigid guardrail beams and non-uniform shoulders. The guardrail beam will simply not follow the contours of the ground beneath it. When shoulder irregularity prevents uniform installation at the standard height, the solution is to drive the offending posts deeper, thus making the guardrail lower at that point. The data show that uniform installations are attainable when the shoulder is uniform, as on interstate highways. If all highways were constructed to the high design standards and under the tight construction controls that apply to interstates, the installation would not be a major cause of low guardrail.

Other causes of low installation are the absence of a height tolerance in the specifications and the Department's lack of formal requirements for inspection of guardrail during installation. The height standard specifies a height of exactly 27 in., and it is very difficult to install a guardrail exactly to a specified height. This fact is generally recognized and, consequently, guardrails that deviate from this height are readily accepted by Department personnel.

Department inspectors perform spot checks using a ruler to measure the height of guardrail directly or a lock level set from the edge of the pavement. General practice is to allow approximately a 1/2-in. tolerance. A final check is made by "eyeballing" the guardrail if it "looks good." If the height deviates more than a little, post-jacking or further driving may be required.* However, as long as the guardrail "looks good" and the height is not "too far off" from the standard, it is accepted to avoid driving up costs.**

Inadequate maintenance contributes to the low guardrail problem in several ways. If soil and vegetation are allowed to build

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*M. B. Vann 1981: personal communication.

**E. S. Coleman 1981: personal communication.

up on the shoulder in front of the guardrail, the effective height of the guardrail is reduced. Soil and vegetation buildup were noted at some of the sites. Sources of soil buildup include sand applications for snow and ice control, fugitive dust and dirt, spills from trucks, and sedimentation of eroded soils. Sources of vegetation buildup include the accumulation of both live and dead vegetative matter and of clippings from shoulder mowing operations. It should be noted that the accumulation of soil and vegetation under the guardrail itself does not create a problem. While measurements in such situations would show the guardrail to be low, the effective height in front of the guardrail may be adequate.

IDENTIFICATION AND ANALYSIS OF REMEDIAL TREATMENTS

The inadequacy of low guardrail has been demonstrated in numerous crash tests (AASHTO 1977; Van Zweden and Bryden 1977; Lampela and Yang 1974; Bronstad et al. 1974; Beaton, Nordlin, and Field 1967; Deleys and McHenry 1967). Vehicles that strike low guardrails tend to vault them, thereby increasing accident severity. Furthermore, an examination of a sample of guardrail installations in Virginia showed that low guardrail is common throughout the state. Over 80% of the guardrails sampled were below the prescribed standard height of 27 in. and some installations were as low as 18 in.

Because of the danger presented by low guardrail to impacting vehicles, corrective treatments must be developed to raise low guardrail up to current safety standards. In this section six corrective treatments are identified and analyzed to determine which would be most feasible under various conditions.

Removal

The first remedial treatment that should be considered is removal of the guardrail. This is accomplished by examining current guardrail warrants to determine if the guardrail is still needed. If the roadside hazard that was being shielded by the guardrail no longer exists, then the guardrail should be removed. Alternatively, if the roadside hazard can be inexpensively removed or sufficiently reduced, then the guardrail should also be removed.

The removal of the guardrail has several advantages. At any particular location, it eliminates the low guardrail problem altogether, it eliminates the hazard of a vehicle striking the guardrail, and it eliminates the need to maintain the guardrail. The disadvantages of removing the guardrail are the expenditures of money, time, and manpower that would be avoided if no action were taken. Because guardrails are themselves hazards, removal should be considered at all locations where they are no longer warranted or where conditions could be changed so that they would no longer be warranted.

Shoulder Adjustment

Guardrail that has become low because of soil and vegetation buildup may be corrected by scraping the shoulder to remove the excess material and thereby increase the effective height of the guardrail. This scraping is generally accomplished by using a motor grader to pull the excess material away from the guardrail toward the pavement where it can be removed. The blade is set for a standard shoulder slope with one end resting on the edge of the pavement. Scraping depths depend on the amount of material to be removed and generally do not exceed 3 or 4 in. Usually, it is possible to scrape to the face of the guardrail. A special attachment to a front-end loader has also been used experimentally for scraping under the guardrail. While the use of the special attachment is costly, time consuming, and disruptive to traffic, those who have used it generally have been pleased with the results.*

Advantages of adjusting the shoulder by scraping are that it is relatively simple and inexpensive, and it can be done as a part of routine maintenance. There are also several disadvantages. The uniformity and depth of grading are dependent on the expertise and judgement of the grader operator, and drainage problems may be created by leaving a berm underneath the guardrail. Furthermore, it may not be possible to scrape enough excess material off to bring the guardrail into conformity with the Department's standard for shoulder cross slope. Pavement overlays may further exacerbate the cross slope constraints. Shoulder scraping should be used in cases where shoulder buildup is the obvious cause of the low guardrail and in cases where the guardrail is not seriously low. Precautions should be taken to prevent drainage problems.

Rail Adjustment

Low guardrail may be corrected by adjusting the rail mounting height on existing posts. This is accomplished by moving or replacing existing block-outs (GR-2 type guardrail) or installing new

*L. F. Pauls and T. Copp 1981: personal communications.

block-outs (GR-1 type guardrail) so that the block-out and rail element extend above the tops of existing posts. This method has been used to a limited extent in several states.* A crash test conducted by Bronstad et al. (1974) showed that thrie-beam guardrail will perform satisfactorily when mounted on extended block-outs. If thrie-beam guardrail is used, the mounting height is less critical and a wider range of vehicle bumper heights can be accommodated.

The primary advantage of adjusting the rail height is that the posts do not have to be adjusted. Correction by rail adjustment has several important disadvantages, the first of which concerns the limited testing and operational experience with this approach. It has been shown that if the block-out is extended below the rail to provide more structural support against the post, a vehicle may snag the block-out. Furthermore, experience with this approach has limited the increase to a maximum of 3 in. Cost data show that this procedure may be nearly as costly as a completely new installation.** Finally, older guardrail installations may be deteriorated such that they could not be fitted with new block-outs, and it would be just as well to replace the entire guardrail. It appears that this treatment would necessarily be limited to those cases where the guardrail is only a few inches low. Further testing and experience are needed to establish the viability of this method.

Post Adjustment

The height of the guardrail may be adjusted by adjusting the height of the post. This could be accomplished by adding an extension to the post; however, this approach appears to be awkward and costly. As an alternative, it may be feasible to pull or jack up existing posts to the required heights. It is not known whether the posts would remain at their new height or eventually settle to their old positions. It is possible that vibrations from passing traffic combined with voids beneath the pulled posts may promote rapid settling.

An advantage to this method is that the whole post would not have to be removed and reinstalled. Disadvantages include the uncertainty about settling, problems with recompacting soil disturbed by the pulling operation, and possible damage to the posts by the pulling operation. In addition, posts may have been bent

*E. S. Coleman 1981: Personal communication.

**E. S. Coleman 1981: Personal communication.

or otherwise damaged during the original installation. The degree to which posts are damaged during installation varies by geographic area. Posts driven in soil common to the eastern part of the state tend to be damaged very little during installation. In the western part of the state, however, it is much less likely that posts would be reusable.* Another consideration for pulling the post is whether the necessary embedment depth would be maintained. Of course, this depth varies with soil type; in stiff soils, embedment is less critical. State standards have not allowed post length to be less than 69 in., which allows a post embedment depth of approximately 42 in. Available literature indicates that embedment depths of 36 to 48 in. are generally adequate for most soils (Michie, Calcote, and Bronstad 1971). The post adjustment method could be especially useful in situations where GR-1 is being upgraded to GR-2. Then the question of settling would be less critical because of the extra support provided by the new intermediate post.

Replacement With Alternate System

Low guardrails may also be corrected by replacing them with alternate systems such as concrete barriers or thrie-beam guardrail, and GR-1 type systems may be replaced with GR-2 type systems. The concrete barriers are commonly used as median barriers on high speed, limited access highways. Thrie-beam guardrail has been used very little in Virginia, although other states are reported to be using it extensively.

Concrete barriers and thrie-beam guardrail are less sensitive to installation height because they are installed higher initially (32 in.). They accommodate a wide range of bumper heights, will accommodate future increases in the height standard, and would not be significantly affected by soil and vegetation buildup and pavement overlays. GR-2 type guardrail is less sensitive than GR-1 in regard to installation height because its block-outs help maintain an adequate height during initial moments of impact. An upgrading of GR-1 and GR-2 would allow the use of existing posts while the new intermediate posts would increase resistance to twisting of the rail under impact.

The primary disadvantage of alternate systems is the extra cost involved. For example, thrie-beam guardrail may cost 35% to 40% more than standard W-beam.** It is questionable whether these higher warrant systems could be justified in many cases.

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*F. L. Rowen 1981: personal communication.

**E. S. Coleman 1981: personal correspondence.

Reinstallation

The final option for correcting low guardrail is to totally remove and reinstall the section at the proper height. The advantage of this method is that it is a proven technology. In addition, the shoulder could be regraded to make it uniform before the guardrail is reinstalled. The only apparent disadvantage of this method is that it is costly.

IDENTIFICATION AND ANALYSIS OF LOW GUARDRAIL

Given unlimited funds, it would be possible to identify and correct all low guardrail in Virginia. However, the economic crunch now facing the Virginia Department of Highways and Transportation, precludes any comprehensive guardrail inventory and correction program. As a result, special mechanisms need to be developed for identifying and correcting those low guardrail situations that are most critical.

Identification of Low Guardrail

As mentioned above, a full-scale inventory of guardrails in Virginia is not practical because of the cost and manpower requirements. Other options, however, are available within existing work schedules and procedures. Identification methods are by no means limited to those presented below; however, each of these methods, or any combination of them, could easily be incorporated into existing programs.

One alternative for identifying low guardrails is to conduct guardrail inspections on those roads that are scheduled for resurfacing or other maintenance work. The state of Maryland uses such an approach as part of its statewide highway safety program. The decline in traffic deaths in Maryland during the period from 1973 to 1977 was partially attributed to this inspection procedure (Maryland Asphalt Paver 1978).

Accident investigations also provide opportunities for identifying low guardrails. In fact, the Virginia Department of Transportation Safety (1976-79) has cited low guardrails in several reports of its crash investigation team. These reports indicate whether low guardrail contributed to the severity of accidents. Accident data also reveal locations where accident frequencies are high and locations where accidents involved guardrail. The investigation of these locations would then determine whether low guardrail was a contributing factor.

Maintenance and mowing crews provide another means for identifying low guardrails. During their regular operations, these crews could inspect guardrails located along their work sections and determine if they are low. Such inspections could also be carried out in response to unsolicited citizen reports. Guardrails that are found to be low could then be reported either formally or informally through appropriate Departmental channels.

The last alternative consists of spot-check inventories conducted by Department personnel at times when work schedules are not pressing. Such spot checks could be systematic or random, and reports would be made when the guardrail was found to be low.

Analysis of Low Guardrail Situations

Criteria for Prioritization System

This section presents a method for determining the degree of hazard associated with low guardrail. A scheme is developed which assigns a numerical score to candidate guardrail installations. This score, once obtained, can be compared to scores or ratings for other low guardrail situations to determine priorities for corrective measures.

The scoring system was developed based on guardrail performance variables, impact probability indicators, and crash severity indicators. In developing the scoring system, two criteria were used: (1) the system must be reasonably simple to apply, and (2) the necessary data must be readily obtainable from field measurements or existing Department sources.

Scoring System

Only the variables considered to be most important were used in the scoring procedure. They fall into two categories: those that apply in all low guardrail situations, and those that apply in only some low guardrail situations. Variables of the first type are guardrail height, vehicle speed, and expected number of encroachments. These were incorporated in the equation given below, with height and speed being normalized by indexing them to maximum values of 10.

$$\text{Score} = W_H H + W_S S + W_N N, \qquad (1)$$

where

W_X = weighting factors for each variable,

H = height index,

S = speed index, and

N = expected number of encroachments.

Variables of the second category include guardrail type, consequence of vehicle vaulting, and soil type. These are not included in the equation since they do not apply in all cases. Instead, they are used in an additive fashion in cases where they do apply.

The height index, H, gives an indication of the probability of vaulting occurring. Lower guardrails are more susceptible to vaulting and, therefore, they are given higher index values. As shown in Figure 5, values for the height index range from 0 to 10. A height of 20 in. was selected for the maximum index value because the typical center of mass of nearly all motor vehicles is above that height (Michie 1981). Guardrails with heights of 20 in. and lower are especially hazardous and should receive the maximum index value. In the absence of any indications to the contrary, the relationship between the index and guardrail height was assumed to be linear. Since the height of the guardrail is likely to vary along the length of the guardrail, an average height should be used.

The speed index, S, indicates both the vaulting potential and crash severity. Studies have shown that at high speeds vaulting is likely to occur and crashes tend to be severe. A moving vehicle's kinetic energy, which must be absorbed or dispelled by a guardrail, is proportional to the square of the speed. Therefore, index values for speed were set proportional to the square of the speed. Posted speed limits in increments of 5 miles per hour were used in calculating the index values with the index for 55 miles per hours, the maximum speed limit in Virginia, being set at 10. If the actual speed is known to be different from the posted speed, then the actual speed should be used. Table 4 gives the speed index values.

The number of expected encroachments, N, indicates how often a guardrail is likely to be hit. The number of encroachments is determined by several factors: (1) the encroachment rate, which is computed as a function of traffic volume; (2) the length of the guardrail; (3) the lateral distance from the guardrail to the edge of the pavement; and (4) the road geometry factor, which accounts for the high frequency of encroachments at the outside of curves. These factors are used to estimate the expected number of guardrail hits using the equation adapted from Hargroves (1981).

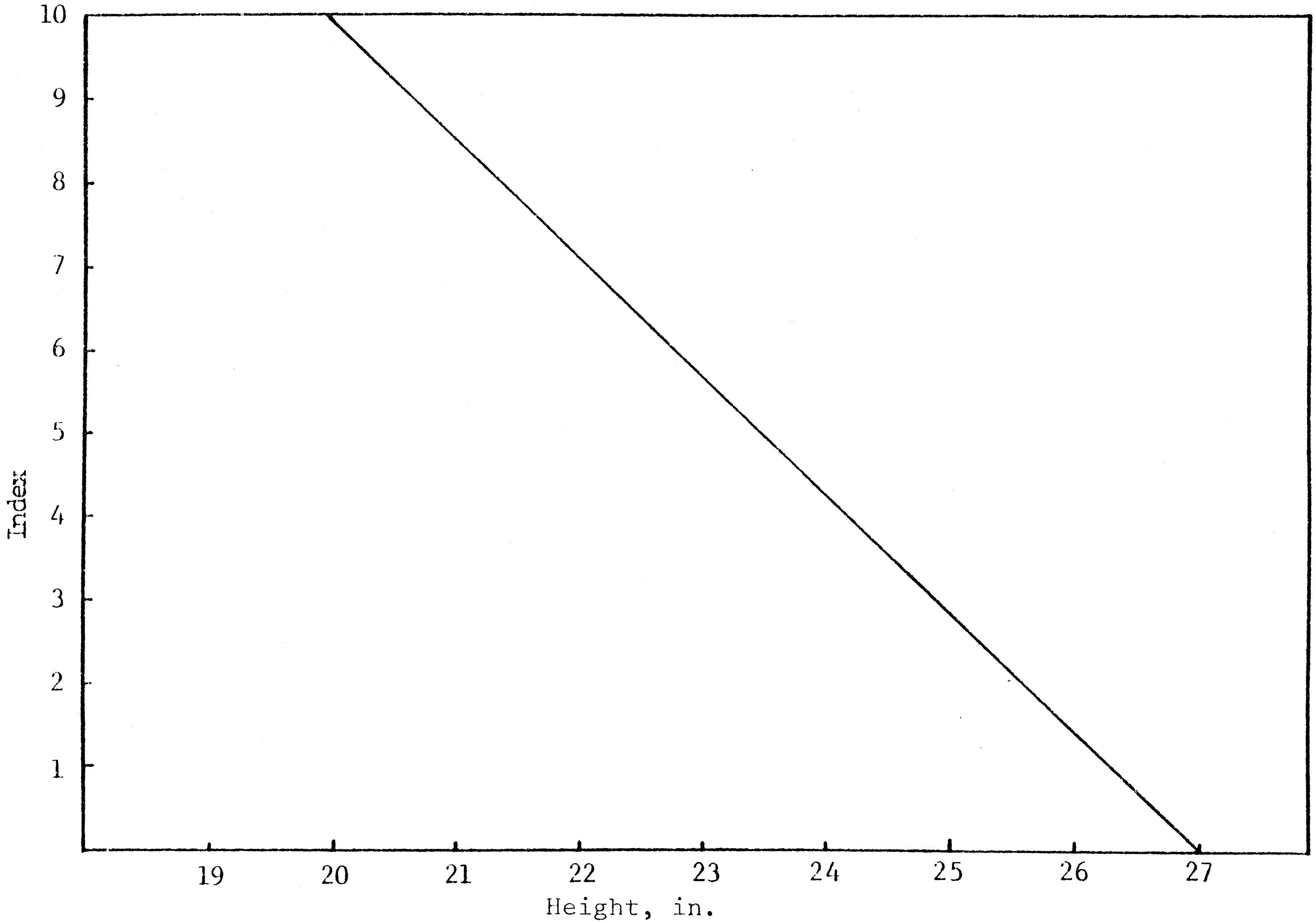

Figure 5. Height index.

Table 4

Speed Index

Speed, mph	Index
25	2.1
30	3.0
35	4.1
40	5.3
45	6.7
50	8.3
55	10.0

$$N = ER \times L/5280 \times LHF \times GF, \qquad (2)$$

where

N = expected number of encroachments per year;

ER = encroachment rate, encroachments per mile per year;

L = length of the guardrail in feet;

LHF = lateral hazard factor; and

GF = road geometry factor, 2 for guardrail on outside of curves greater than 3°, 1 otherwise.

The encroachment rate, ER, is the frequency at which vehicles run off the road. It is different for each side of the highway and is calculated by another equation adapted from Hargroves (1981).

$$ER = \frac{\text{Side}}{3}\,(10 + 1.53\ \text{ADT}), \qquad (3)$$

where

Side = 1 for left side of road, for use on divided highways;

= 2 for right side of road, for use on divided highways;

= 3 for both sides of road, for use on undivided highways; and

ADT = average daily traffic in thousands.

The length of the guardrail is measured in feet. This factor, when divided by 5,280, converts encroachments per mile to encroachments for the given length of the guardrail.

The number of encroachments on a fixed object varies with the distance of the object from the pavement. The adjustment for this distance is given by the lateral hazard factor in Table 5.

The road geometry factor, GF, is included because encroachments are more frequent on the outside than on the inside of curves, especially for those greater than three degrees. In addition, sharp horizontal curves increase the likelihood of high impact angles and, consequently, greater accident severity.

Typical values of N vary from 0 to 10. Since N exceeds 10 only under extreme circumstances (i.e., high traffic volumes, long guardrails, and curves greater than three degrees), a maximum value of 10 is used.

As noted above, three of the pertinent variables were not included in the scoring equation because they do not apply in all cases. Nevertheless, in the cases to which they do apply, they have an additive effect on the degree of hazard presented by the guardrail and should be reflected in the total scores.

A review of the literature review made in conjunction with this study (Tyler 1981) indicated that GR-1 type guardrail (i.e., non-blocked-out, 12.5 ft. post spacing) is inferior to GR-2 type guardrail (i.e., blocked-out, 6.25 ft. post spacing), and therefore, has a bearing on the degree of hazard. In addition, the data showed that most of the lowest guardrail in Virginia is GR-1, which indicates that it is more of a problem than GR-2. Additional consideration should, therefore, be given to the correction of GR-1 type guardrails.

Table 5

Lateral Hazard Factors

Distance From Road, feet	Lateral Hazard Factor
0 - 5	0.98
5 - 10	0.90
10 - 15	0.77
15 - 20	0.63
20 - 25	0.49
25 - 30	0.38

Source: Developed from Hargroves (1981).

Catastrophic consequences of vehicle vaulting are probable when the guardrail is protecting a severe drop-off. Additional weight should, therefore, be added to low guardrail situations where catastrophic consequences are probable.

As indicated earlier, poor soil types, such as sandy loam, may contribute to the failure of guardrail because of inadequate post embedment. In poor soils, the posts rotate easily and cause the guardrail to deform sufficiently for an impacting vehicle to vault over it. Poor soils have an even worse adverse effect if the guardrail is low. Therefore, this factor should also be considered in the prioritization scheme.

The weighing factors in equation (1) were determined to indicate the relative importance of each of the variables. Since insufficient information was available to quantitatively derive these factors, they were developed subjectively based on the following considerations.

1. Maximum score should be 100.

2. The height index, H, should have the highest weight.

3. The speed index, S, and number of encroachments, N, should have equal weights.

The incorporation of these considerations resulted in H being assigned a weight of 4 while S and N were each assigned weights of 2. Equation (1) then becomes

$$\text{Score} = 4H + 2S + 2N. \quad (4)$$

The values to be added for the three minor variables are as follows: GR-1 type guardrail adds a value 10; catastropic consequences add a value of 10; and poor soil conditions add a value of 5.

Soil type was considered to be the least important variable, and therefore, it was assigned the lowest value. The values assigned to these variables appear to be reasonable. Since only one, or at most two, of these variables would typically apply at any location, their contribution to the total score would be much less than that of the major variables. On the other hand, given two comparable situations, one with GR-1 and one with GR-2, the additive effect of the guardrail type variable would give priority to correcting the GR-1 type guardrail. Likewise, the additive effect of the catastrophic consequences factor would show that those situations with severe drop-offs should be given priority.

A number of typical as well as minimum and maximum scores were calculated to establish the validity of the formula. The calculations showed that the scoring system works reasonably well in establishing priorities for those low guardrail situations that are most hazardous.

Example Application

The following example demonstrates the use of the scoring system to compare two low guardrail situations.

Site Data

At site number one, a low GR-1 type guardrail is identified on a straight section of a 2-lane highway with an ADT of 12,000 vehicles. The guardrail is 22 in. high and 1,000 ft. long. The distance from the edge of the pavement to the guardrail is 12 ft. and the posted speed limit is 55 miles per hour.

At site number two, a low GR-2 type guardrail is identified on a straight section of an interstate highway with a one-directional ADT of 20,000 vehicles. The guardrail is located 12 ft. from the right-hand edge of the pavement and has a height of 25 in. and length of 1,000 ft. The posted speed limit is 55 miles per hour.

Solution

Starting with equation (4),

$$\text{Score} = 4H + 2S + 2N \text{ ---------------------------} (4)$$

values for each variable are determined for site number one. From Figure 5, H is equal to 7.2. From Table 3, S is equal to 10. From equation (2), N is calculated as

$$N = ER \times L/5280 \times LHF \times GF, \text{--------------------} (2)$$

where

$$ER = \frac{Side}{3} \ [(10 + 1.53 \ ADT \ (thousands)],$$

$$= \frac{3}{3} \ [(10 + 1.53 \ (12)],$$

$$= 28.36.$$

L is 1,000 ft. and LHF from Table 4 is 0.77. GF is 1 since the guardrail is on a straight section of road. Substituting all these values into equation (2), N is equal to 4.1. Substituting the values into equation (2), N is equal to 4.1. Substituting the values H, S, and N into equation (1), a score of 57.0 is obtained. Since the guardrail is type GR-1, the score is increased by 10 to give a total score of 67.0.

For site number two, Figure 5 shows that H is equal to 2.8. From Table 3, S is equal to 10. Again using equation (2), N is calculated as:

$$N = ER \times L/5280 \times LHF \times GR, \text{-------------------------} (2)$$

where

$$ER = \frac{Side}{3} \ [(10 + 1.53 \ ADT \ (thousands)],$$

$$= \frac{2}{3} \ [10 + 1.53 \ (20)],$$

$$= 27.07.$$

L is 1,000 ft. and LHF from Table 4 is 0.77. GF is 1 since the guardrail is on a straight section of road. Substituting all these values into equation (2), N is equal to 3.9. Substituting the values H, S, and N into equation (1), a score of 39.0 is obtained.

A comparison of the scores for the two sites shows that site one is more hazardous than site two and should, therefore, be corrected first. This assumes, however, that there is no significant difference in the cost of the remedial treatments.

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APPENDIX

GUARDRAIL SITE INFORMATION

Date ______________________ Route ______________________

County ____________ District ____________ Site Location ____________

Milepost ____________ Pavement Width ____________ Shoulder Width ____________

Horizontal Alignment ______________ Vertical Alignment ______________

Type of Area ______________ Posted Speed Limit ______________

Type of Vehicle Traffic ______________________________

Height of Guardrail (1) ____________ (2) ____________ (3) ____________

Condition of Shoulder ______________________________

Condition of Guardrail ______________________________

Type of Pavement ______________________________

Has Pavement Recently Been Overlaid? ______________________________

Has Guardrail Been Adjusted to Proper Height? ______________________________

Describe Area Around Guardrail ______________________________

____

____

Remarks ______________________________

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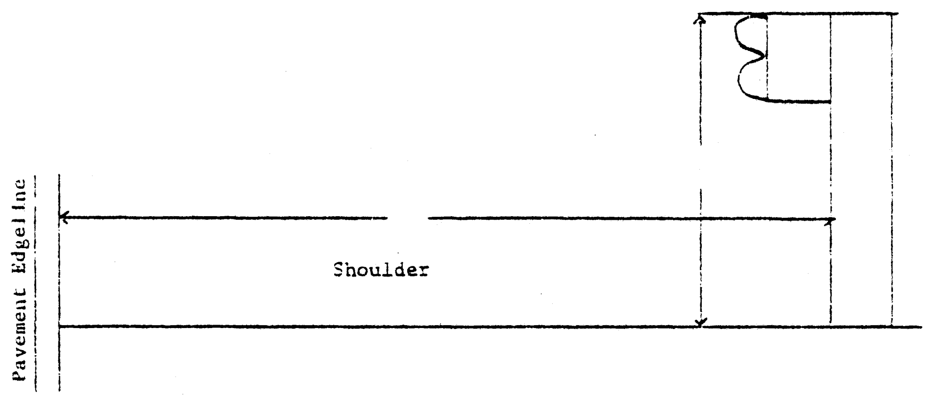
GUARDRAIL SKETCH

Date ____________ Route ______________ County ____________

District ______________________ Site No. ___________________



Type of Shoulder ____

Slope of Shoulder ____

Remarks ____

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