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Rockfall Hazard Rating System

Participant's Manual

National Highway Institute

TECHNOLOGY APPLICATIONS

Innovation Through Partnerships

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16. Abstract

Development of the Rockfall Hazard Rating System (RHRS) is complete. The system has been fully tested and implemented by the Oregon Department of Transportation. The RHRS is a process used in the management of rockfall sites adjacent to highways. The system is proactive by design, providing a rational way to make informed decisions on where and how to spend construction funds in order to reduce the risks associated with rockfall.

This Participant's Manual documents the components of the RHRS, the steps an agency should follow to implement the system, and discusses the level of commitment required. The benefits of implementation and the limitations of the system are also described. The manual serves as both a field guide and as a desk top reference for those who perform the slope ratings and those who use the resulting database in establishing rockfall remediation designs and construction priorities.

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PREFACE

Many miles of highway have adjacent rock slopes that are subject to rockfall. This potential for rockfall is due in part to past construction practices that relied on overly aggressive excavation techniques. Although these practices facilitated removal of broken material, they commonly resulted in slopes more prone to rockfall than necessary.

The Rockfall Hazard Rating System (RHRS) is intended to be a tool that will allow transportation agencies to address their rockfall hazards proactively instead of simply reacting to rockfall accidents. The RHRS provides a legally defensible, standardized way to prioritize the use of the limited construction funds available by numerically differentiating the apparent risks at rockfall sites.

The Oregon Department of Transportation (ODOT) began developing the RHRS in 1984. Funding from a Federal Highway Administration (FHWA) sponsored, pooled-fund, Highway Planning and Research (HPR) Grant allowed ODOT to complete development of the system and test it at more than 3,000 sites.

The workshop at which the RHRS is presented is intended for the those personnel who will implement the RHRS and be responsible for evaluating and rating the rockfall sites, and for the managers who will decide whether their agency should adopt the RHRS. For these managers, the first chapter and hour of the workshop is an executive summary.

Those participants who will implement and perform the RHRS will receive two days of training. Their first day will be spent in a classroom setting, where they will learn how to perform the ratings, create a rockfall database, and use that information to set rockfall remediation priorities. Their last day's task will be a hands-on field exercise that requires the participants to apply the RHRS's process at two actual rockfall sites within the agency's jurisdiction.

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CHAPTER 1: EXECUTIVE SUMMARY

1.1 Introduction

As transportation agencies, we are expected to provide a safe highway system for the public. This is never a simple objective to accomplish. The difficulty is compounded in areas where our highways pass through terrain requiring rock cuts. In mountainous states like Oregon, many miles of roadway pass through steep terrain where rock slopes adjacent to the highway are common. Some of these manmade slopes are over a 100 feet high. Many are situated near the base of rugged natural slopes that extend hundreds of feet further upslope.

Rockfall potential is inherent in these areas. This potential is partially the result of how the highway system has evolved. Until recently, standard practice was to use overly aggressive blasting and ripping techniques to construct rock slopes. Although this practice facilitated excavation, it frequently resulted in slopes more prone to rockfall than necessary. Where these conditions exist, agencies are faced with the difficult task of reducing the risk of rockfall.

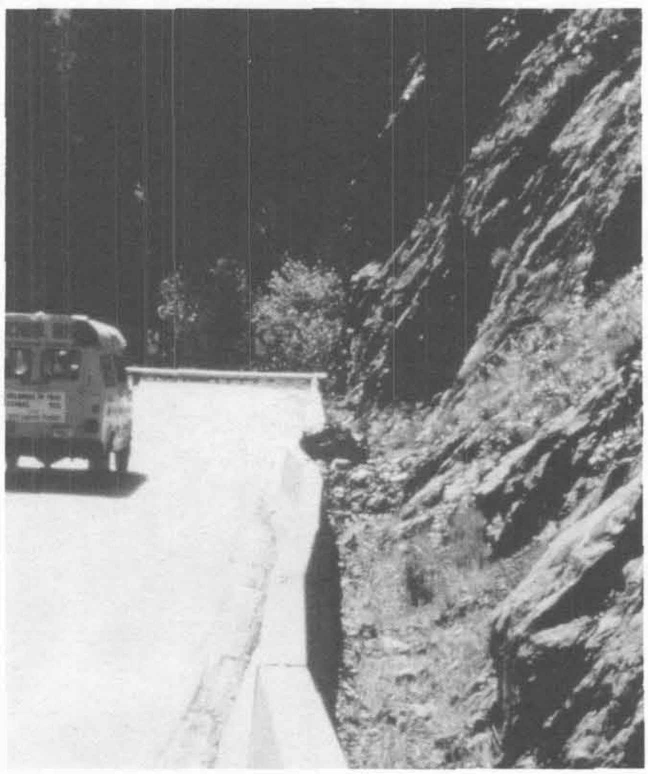


Figure 1.1 The public expects a safe trip.

ODOT's management and legal counsel recognized the value of having a systematic way to set rockfall project priorities and allocate limited repair funds. To be effective, the program would begin with an inspection of all rock slopes along the highway system to identify areas where rockfall would most likely affect the roadway. Once identified, these sections would be rated relative to each other, by trained personnel, to determine which presented the greatest risk to the public. To accomplish this goal, a rating system was needed.

1.2 Evolution of the Rockfall Hazard Rating System

ODOT began to discuss the need for an RHRS in 1984. As part of an initial literature search on the subject, a paper written by C. O. Brawner and Duncan Wyllie (1) was reviewed. The authors had developed rating criteria and a scoring method following a very severe railroad accident caused by a rockfall event. The intent of their system was to be proactive in assessing rock slopes adjacent to the railroad to identify where rockfall remediation was needed and to prioritize the work. Using this approach, rockfall sections were grouped into A, B, C, D, and E categories based on their potential for rockfall events and on the expected effects.

Figure 1.2 Railroad accident caused by a rockfall.

In a subsequent paper (2), Wyllie outlined a more detailed rating procedure for prioritizing rockfall sites. Wyllie's approach included specific categories for evaluation. The categories were scored using an exponential scoring system.

These were the two approaches utilized in developing the prototype for the RHRS. From the earlier work of Brawner and Wyllie, the idea of grouping sites in accordance with a subjective evaluation was adopted as part of the preliminary rating. From Wyllie's later work, the rating sheet format with categories and the exponential scoring system were adopted as part of the detailed rating. Some of the categories are similar to Brawner's and Wyllie's while others are new. All have been modified based on experiences in developing and applying the RHRS statewide over the past several years. Detailed "narratives" of the rating criteria have been added to promote consistent understanding and application of the system.

The final phase of RHRS development began in July 1989, when ODOT was selected to perform the HPR pooled-fund study entitled the Rockfall Hazard Rating System. Funding support for the study was provided by the following agencies:

State Highway Departments

1. Arizona
2. California
3. Idaho
4. Massachusetts
5. New Hampshire
6. New Mexico
7. Ohio
8. Oregon
9. Washington
10. Wyoming

Federal Highway Administration

1. CTIP (Direct Federal)
2. Office of Implementation
3. Office of Research

The goal of the study was to finalize an effective RHRS. Creation of the system was guided, and its value judged according to several criteria:

1. Was the system understandable and easy to use?
2. Did the narratives adequately explain the criteria?
3. Could several different raters achieve uniform results?
4. Did the scores adequately reflect the rockfall hazard?

Through full-state implementation, the RHRS was tested at more than 3,000 sites. The narratives were finalized and forms and rating aids were developed. All pertinent information was documented in the RHRS User's Manual (3). Nationally, the test results were shared with State Highway Departments through workshops presented at five regional Geotechnical Conferences sponsored by the FHWA.

The ODOT's engineering geology staff spent many hours designing, testing, and redesigning the Rockfall Hazard Rating System. Their specialized background and understanding of rockfall made them uniquely qualified to create and maintain the RHRS system and database.

1.3 Summary of System Features

The RHRS is a process that allows agencies to actively manage the rock slopes along their highway system. It provides a rational way for an agency to make informed decisions on where and how to spend construction funds. The six steps in the process are summarized below.

1. Slope Inventory - Creating a geographic database of rockfall locations (chapter 2).

2. Preliminary Rating - Grouping the rockfall sites into three, broad, manageably sized categories as A, B, and C slopes (chapter 3).

3. Detailed Rating - Prioritizing the identified rockfall sites from the least to the most hazardous (chapters 4 and 5).

4. Preliminary Design and Cost Estimate - Adding remediation information to the rockfall database (chapter 6).

5. Project Identification and Development - Advancing rockfall correction projects toward construction (chapter 7).

6. Annual Review and Update - Maintaining the rockfall database (chapter 8).

Note that the RHRS uses two types of slope ratings: the preliminary rating performed during the initial slope inventory, and the detailed rating. The preliminary rating eliminates many slopes from any further consideration. This staged approach is the most efficient and cost effective way to implement the RHRS and is especially useful where agencies have responsibility for many slopes with a broad range of rockfall potential.

1.4 RHRS Benefits

The benefits associated with a fully implemented Rockfall Hazard Rating System fall under three main headings:

1. Knowledge
2. Public Perception
3. Legal Protection

The "bottom line" of all three is that the necessary steps are being taken to understand the problem, and that the agency is actively dealing with its rockfall problems.

1.4.1 Knowledge

Through implementation of the RHRS, management obtains detailed information and a uniform process that can help them make practical decisions on where to allocate money for rock-slope projects. Until an agency knows the extent of its rockfall-related problems, it cannot reasonably plan to deal with them. As in all successful planning activities, a thorough understanding of the problem is required.

Oregon DOT's experience with the Rockfall Hazard Rating System has been favorable. They welcome having quality information to use in this area of project development. The agency believes the issue of public safety is being properly addressed and that greater legal protection is afforded the agency by having the RHRS in place.

1.4.2 Public Perception

The public has come to realize that many risks are associated with driving and that most of these risks are the result of human error. In this respect, rockfall related accidents are out of the ordinary. Very few highway accidents receive as much adverse public attention as one caused by a rockfall. We are expected to do something about the problem.

To offset this reaction, an agency must demonstrate to the public that it is not only aware of the rockfall problem but is also taking prudent steps toward reducing rockfall risks. The RHRS is now recognized as an effective system for dealing with rockfall. Using such a system demonstrates that the agency is aware of its safety obligations and is taking a proactive approach to the issue of rockfall.

1.4.3 Legal Protection

The courts have indicated that it is unreasonable to expect an agency to have at its disposal enough funds to deal with all safety related issues at any given time. However, a system must be in place by which needed safety projects, including rockfall remediation projects, can be identified and developed as funding is made available. ODOT's experience has indicated that this position is legally defensible.

The recently implemented RHRS has not been tested in court to date. However, Oregon has for many years had a priority list for developing rockfall construction projects. The sites listed were those identified as having a history of accidents and/or excessive maintenance costs. The list generally contained only about 100 sites, selected not for their rockfall potential but for their rockfall history. The sites were prioritized on the basis of a benefit/cost analysis. Even so, because ODOT had a definite, planned approach to deal with rockfall sites as funds were made available, litigations brought against the state because of rockfall were either settled out of court or resulted in findings favorable to the state. Having a federally recognized, state-of-the-art process for developing the priority list will serve agencies even better in this regard.

1.5 Implementation

The RHRS process requires a greater commitment and focus on the rock slope issue than is commonly the norm for many agencies. The needed commitment entails additional working hours and dollars to train the staff, complete the initial survey, update the database regularly, and develop remedial programs aimed at reducing the rockfall risk at the worst sites.

Several steps are recommended for an agency to successfully implement the RHRS. These steps can be grouped under the following two headings:

1. RHRS modification.
2. Staff Training.

Some customization of the RHRS may be necessary. In addition, a properly trained and experienced staff is needed to perform the slope evaluations and to develop remedial designs. The associated costs will vary, depending on an agency's past experience in relation to the process, its staff resources, and the number of rock slopes it must evaluate.

1.5.1 RHRS Modification

It is understandable that some modifications are inevitable. Keep in mind, though, that the RHRS is a highly developed system. Thinking through major modifications and retracing many of ODOT's and FHWA's efforts will likely prove to be unnecessary.

Within an implementing agency, a committee comprised of representatives from the geotechnical, maintenance and project development sections is helpful in guiding implementation of the RHRS. This guidance helps to ensure that the finished product is in the most useable form possible.

Consistency is an important aspect of the standard RHRS. Any necessary modifications should be completed prior to full-scale implementation. These modifications might include:

- Changes to the basic RHRS to accommodate local conditions.

- Alterations in one or more of the data collection forms, graphs or work sheets.

- Changes to the Rockfall Database Management Program (RDMP), or development of the agency's own database system.

Naturally, neither the scope of the rockfall problem nor the physical conditions that cause it are the same in every agency. The detailed rating portion of the system evaluates the physical and historical conditions at a site. The criteria established for the ratings is based on a wide spectrum of possible conditions. If the conditions in your area are not covered by the proposed criteria or if the majority of the slope conditions fall at one end of the spectrum, then a modification of the criteria is recommended. This change will allow for adequate score separation and better identification of the more hazardous sites.

For example, in the slope height category, using the established criteria, a slope must exceed 105 feet in height in order to receive the maximum score of 100 points. If very few slopes in your area are this high, then differentiating the relative risks associated with this category through adequate score separation will not occur. The criteria should be adjusted to avoid this

The forms in this manual were created to suit the requirements of the RHRS and the RDMP. However, agencies typically differ both in the way they are organized and the way the document geographic information. Modifying the forms to conform to an agency's normal procedures may be necessary.

If the scoring criteria are altered, the exponent formulas used to calculate a score based on the measured criteria will also need to be modified. These formulas have been used to produce scoring graphs and tables that facilitate the rating process. The scoring graphs and tables will need to be redeveloped if criteria changes are made.

A computer database is an important part of the RHRS. A great deal of information will be generated that must be readily accessible. In addition, since there are many ways of using the RHRS data, having the flexibility to present the data in several different formats is important. A hard copy file system will not meet this need.

The FHWA has developed a Rockfall Database Management Program (RDMP) that is PC based and designed specifically for the RHRS. The program is a stand alone database that requires no supporting software. A copy is provided at no charge to the states. The program operations are quite user friendly. The RDMP is an excellent tool, and is highly recommended. If assistance is needed to tailor the RDMP to an agency's needs, that help is available through the FHWA.

If an agency already has a mainframe database system, it may want to adapt it to include the RHRS information. Being able to network through a statewide system offers the advantage of allowing rapid transfer of information.

1.5.2 Training

Successful completion of the RHRS depends on the efforts of many people. The staff of raters, data entry personnel, and designers all need training. In Oregon's case, all these duties were performed by its staff of engineering geologists. They helped develop the RHRS, performed the ratings, entered the data, and prepared the preliminary designs and cost estimates. Because of proper training, they have since successfully demonstrated that reasonable and repeatable slope ratings can be achieved and quality preliminary designs produced.

The responsibility for slope evaluations and design concepts should rest with the more experienced staff. Training should consist of both a classroom style introduction to the RHRS and additional hands-on field training beyond what was provided during the second day of this course. Joint field exercises will help the group reach a consensus on how to apply the criteria. Communication within this group during implementation will help maintain consistent application of the RHRS.

Prior to full-scale implementation, several rockfall sites should be identified for rating. The sites should be selected to provide as wide a variety of conditions as possible. Each rater should rate all of the sections independently. A peer review of the results should be undertaken to insure uniform application of the criteria. (A smaller group of raters will promote more consistent, reproducible, and useable results than a larger group.) It is best to make any final modifications to the RHRS or operational procedures at this time.

If a mainframe system is used, input of the RHRS information into the database may be assigned to data entry personnel. Their familiarity with data entry can reduce the training cost of this effort to nearly zero. However, utilizing the extra staff to ensure that the data is understandable to these individuals may not make it the best option. If the raters input the data, some time will be needed to familiarize them with the procedure. The PC based RDMP database system was made as user friendly as possible which should minimize the required training.

Developing state-of-the-art preliminary designs and cost estimates is a specialized skill. This function may be outside an agency's capabilities and may require contracting out. If the agency's staff is capable in this area only routine review is required, and little or no training will be necessary. Because the designs are preliminary, less experienced raters may produce these design concepts as long as their work is closely reviewed by a qualified in-house specialist. The new experience gained by these raters will be beneficial.

1.5.3 Costs

Cost is a primary concern for any agency considering commitment of their resources to this kind of effort. The costs associated with this commitment are jointly dependant on an agency's pay scales and the scope of the rockfall situation. One way for an agency to estimate its costs is through comparison with Oregon's (in 1990 dollars). The following tables detail ODOT's implementation costs.

Table 1.1 ODOT'S RHRS Costs (7/01/90)

Class	Middle Pay Step (Loaded Rate)		Hours Charged		Total
Geologist 1	$21.81/hr.	x	878.5	=	$19,160.08
Geologist 2	$24.01/hr.	x	793.0	=	$19,039.93
Geologist 3	$27.84/hr.	x	164.0	=	$ 4,565.76
Supv. Geol.	$30.72/hr.	x	448.0	=	$13,762.56
Office Spec.	$16.25/hr.	x	44.5	=	$ 723.12
Eng. Tech. 1	$16.29/hr.	x	139.0	=	$ 2,264.31
Maint. For. 2	$17.42/hr.	x	960.0	=	$16,732.00
Transp. Eng. 1	$24.01/hr.	x	80.75	=	$ 1,942.11
Total Overtime	$ variable	x	66.5	=	$ 1,654.65
Expenses				=	$ 7,325.00
			Total		**$87,169.52**

Table 1.2 Description of Work Completed

Number of Slopes	Work Performed
3000*	Total slopes inventoried statewide. All were assigned an A,B,C rating.
1340	Slopes that were identified as A or B slopes and were entered into the RHRS database.
501	Slopes that were designated as A slopes and were further evaluated using the detailed rating.

* Estimated, since "C" rated slopes were not documented.

Table 1.3 Time Expenditures

Personnel Involved	Time
All	3493.5 hrs. or 436.68 days
Geologists (only)	2283.5 hrs. or 285.00 days

Table 1.4 Breakdown of Expenses

Slope Type	Cost Per Slope*
All "A", "B", "C" cuts	$ 29.00 spent per cut rated
"A" and "B" cuts only	$ 65.00 spent per cut rated
"A" cuts only	$174.00 spent per cut rated

* Total cost/no. of slopes in grouping.

Table 1.5 Expenditures Based on Percent of Time Spent for Each Step

Category	Suggested*	ODOT #(actual)	Cost/Step (ODOT)
Training	10%	2%	$ 1,743.39
Prelim. Rating	50%	53%	$46,199.84
Detailed Rating	30%	31%	$27,022.55
Design/Cost Est.	10%	14%	$12,203.73

* Suggested as a guideline for implementing the RHRS. Actual percentages will vary from agency to agency.

When completed, the final RHRS product is a statewide database that identifies all "A" and "B" rated slopes and includes a preliminary design and cost estimate for all of the "A" rated slopes. Table 1.4 indicates that the expenditure to complete this estimate, based solely on the number of "A" rated slopes, is $174.00 per slope. This cost is quite reasonable.

1.6 Limitations

Agencies will always be expected to react to rockfall accidents, no matter where the accident area ranks on the RHRS priority list. The tendency to overreact should be resisted. Sites where an accident has occurred should be reevaluated using the detailed rating to determine if the rockfall incident has increased or decreased the rockfall potential. The level of investment at the site should be consistent with the newly evaluated rockfall potential relative to the other sites.

The Rockfall Hazard Rating System offers agencies a method to prioritize their rockfall problems by providing a relative rating among slopes. This rating is partially subjective. Although the slope evaluation process is as straightforward as possible, there is still a range of values that a particular slope could receive. This depends to a large degree on the abilities of the raters and how consistently they interpret and apply the rating criteria. Keep in mind that any "A" rated slope is capable of sending rock onto the roadway, whether it receives a detailed rating score of 700 or 600 points.

1.7 Conclusion

Oregon's experience with the RHRS has been favorable. The response by agency management has been one of relief and acceptance. They welcome having quality information to use in this area of the project development process. They can now make rational decisions on where to allocate money for rock slope projects, a capability that was not possible before implementation of the Rockfall Hazard Rating System.

CHAPTER 2: SLOPE SURVEY

2.1 Purpose

The purpose of the slope survey is to gather specific information on where rockfall sites are located. This first step is an essential feature of the RHRS. Only through this effort can an agency understand the extent of the rockfall problem it faces.

2.2 Approach

It is best to approach the survey without preconceived ideas of the location or number of hazardous sites. Few people will already be aware of even the most critical rockfall sections statewide.

The slope survey is an information gathering process that, in the beginning, may seem unreasonably burdensome. It is best to break the effort into manageable tasks. Using existing maintenance boundaries is a practical starting point.

Accurate delineation of the rockfall section is important. For the purpose of the RHRS, a rockfall section is defined as:

> **Any uninterrupted slope along a highway where the level and occurring mode of rockfall are the same.**

The limits of a rockfall section are established by the length of the slope adjacent to the highway. Interruptions in the slope may be due to numerous factors such as drainages, cross roads, and topography.

Within an uninterrupted section, the level (frequency and/or amount) of rockfall can be markedly different. Two examples of these differences are a change in the frequency or orientation of the discontinuities and a difference in erosion rates. Where this kind of variation occurs, the urgency and type of remediation required may vary enough to make delineating portions of the slope as separate rockfall sections appropriate.

The rockfall mode (the reason for the rockfall) may also vary. Changes in rock type, slope geometry, or the size of the fallout area can occur throughout an uninterrupted slope section. Thus, the slope can have different material properties exposed, or varying conditions that lead to rockfall on the highway. The type of remediation will vary frequently because of these variations and delineating additional sections is appropriate.

Establishing rockfall sections in this manner requires both skill and effort. The desired result is a flexible and usable database. Grouping of sites can occur later, if needed, when project limits are defined during the project development process.

2.3 Personnel

Two people are needed for the slope survey: the rater, who will perform the preliminary rating and, if needed, the detailed rating, and a person from highway maintenance. The maintenance person should be the one who is most knowledgeable about a highway's rockfall history and associated maintenance activities.

2.4 Information Gathered

The historic perspective provided by the maintenance person is an important element of the preliminary rating. Past rockfall activity is a good indicator of what to expect in the future. Too often, the rockfall history of a site is not well documented, and is maintained only in the memory of the person who works on that section of highway. The slope survey provides an opportunity to document the historic rockfall activity. The following information should be covered:

1. Location of rockfall activity
2. Frequency of rockfall activity
3. Time of year when activity is highest
4. Size/quantity of rockfall per event
5. Physical characteristics of rockfall material
6. Where rockfalls have come to rest
7. Available accident history
8. Opinion of rockfall cause
9. Frequency of ditch cleaning/road patrol
10. Estimated cost of maintenance response

This information should be recorded in the Comments section of the field data sheet shown on the next page.

RHRS FIELD DATA SHEET

HIGHWAY: REGION:

HIGHWAY # ________	Beginning M.P. ________	L / R	Ending M.P. ________
COUNTY # ________	DATE ________	NEW	Rated By ________
CLASS A B	ADT ________	UPDATE	Speed Limit ________

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height ________ ft °/ °/		SLOPE HEIGHT	________
Ditch Effectiveness G M L N		DITCH EFFECT	________
Average Vehicle Risk %		AVR	________
Sight Distance ________ ft Percent Decision Site Distance %		SIGHT DISTANCE	________
Roadway Width ft		ROADWAY WIDTH	________
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1		CASE 1	
Structural Condition D C/F R A		STRUCT COND	________
Rock Friction R I U P C - S		ROCK FRICTION	________
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	________
Difference in Erosion Rates S M L E		DIF ER RATES	________
Block Size/Volume ft/yd^3		BLOCK SIZE	________
Climate Precipitation L M H Freezing Period N S L Water on Slope N I C		CLIMATE	________
Rockfall History F O M C		ROCKFALL HISTORY	________
		TOTAL SCORE	

COMMENTS:

At the top of the data sheet, the highway name and number, the region or district, the beginning and ending mile point, whether the section is left or right of centerline, the county, the date, and the rater's name, should be recorded. The limits of the rockfall section should be determined to the nearest hundredth of a mile.

CHAPTER 3: PRELIMINARY RATING

3.1 Purpose

The purpose of the preliminary rating is to group the rockfall sections inspected during the slope inventory into three broad, more manageably sized categories. Without this step, many additional hours would be spent applying the detailed rating at sites with only a low-to-moderate chance of ever producing a hazardous condition. This rating is a subjective evaluation of rockfall potential that requires experienced, insightful personnel to make valid judgments.

3.2 Criteria

The criteria used in the preliminary rating to categorize sections as "A," "B," or "C" slopes are shown below.

Table 3.1 Preliminary Rating System

CLASS CRITERIA	A	B	C
ESTIMATED POTENTIAL FOR ROCKFALL ON ROADWAY	HIGH	MODERATE	LOW
HISTORICAL ROCKFALL ACTIVITY	HIGH	MODERATE	LOW

The RHRS is a proactive system, primarily aimed at the rockfall potential at a site. The "estimated potential for rockfall on roadway" criterion is therefore the controlling element of the preliminary rating. For example, if a slope presents a high potential for rock on the roadway, (i.e., the slope contains a large block that displays evidence of active displacement and very limited fallout area is available), it would receive an "A" rating, regardless of other past rockfall activity. The "historical rockfall activity" criterion is used as a supplement to the preliminary rating, where clarification is needed. For example, assume, after inspecting a site that it is unclear whether to classify a slope as an "A" or "B" slope on the basis of rockfall potential. The maintenance person confirms that although the rockfall activity has decreased in recent years, it is still high. The slope should be rated as an "A" slope.

3.2.1 Estimated Potential for Rockfall on Roadway

When rating the estimated potential for rockfall on roadway the following factors should be considered:

1. Estimated size of material
2. Estimated quantity of material/event
3. Amount available
4. Ditch effectiveness

3.2.2 Historical Rockfall Activity

When rating the historical rockfall activity, the following factors should be considered:

1. Frequency of rockfall on highway
2. Quantity of material
3. Size of material
4. Frequency of clean-out

3.3 Classification Description

A "C" rating means either that it is unlikely that a rock will fall at this site or that, if one should fall, it is unlikely to reach the roadway. In other words, the risk of a hazardous situation occurring is nonexistent-to-low. On the following page is an illustration of a typical "C" rated slope. Note that even if a rock were released from the slope, the chances of its reaching the roadway are almost nonexistent. It is not worthwhile to clutter the database with information on slopes of this nature.

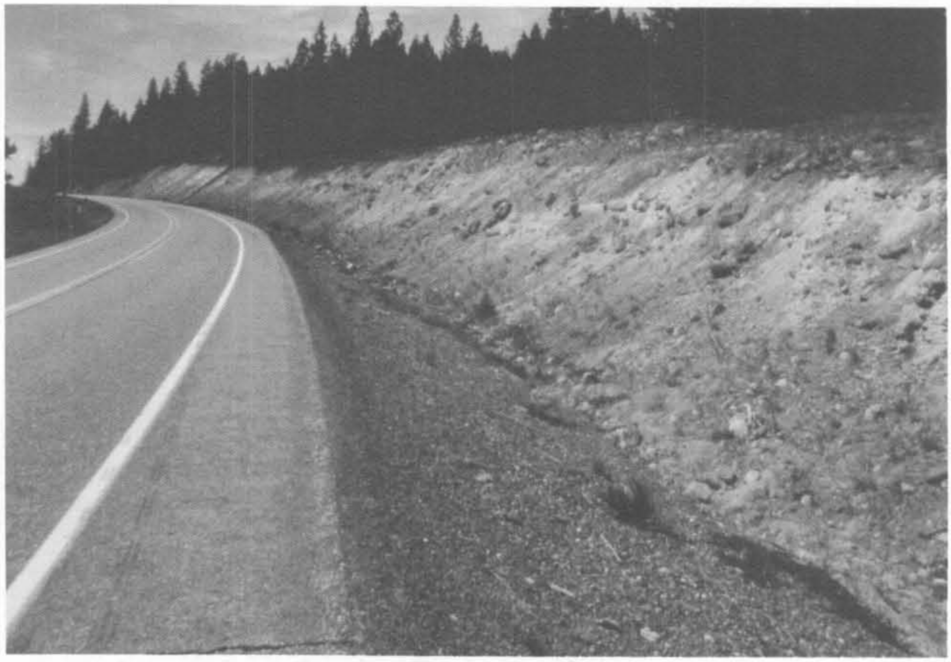


Figure 3.1 "C" rated slope.

As the rating increases to a "B", the risk ranges from low to moderate. The following photograph shows a typical "B" rated slope. Although rockfall from the slope is certainly possible, the fallout area is large enough to restrict nearly all of the rockfall from reaching the roadway. Rock on the roadway at this location would be a rare occurrence.

Figure 3.2 "B" rated slope.

For "A" rated sections, the risk ranges from moderate to high. The example shown below is an obvious "A" rated slope. Note that there is a nearly inexhaustible supply of rock on the slope and nowhere for it to fall except onto the roadway. In addition, sight distance is insufficient and the roadway is quite narrow.

Figure 3.3 "A" rated slope.

Consistency in applying the criteria is important. The ability and the comfort levels associated with these decisions improve with experience. Once rated, all rockfall sections that have received an "A" rating should be photographed. These photographic records are useful later when preliminary design concepts are discussed and are especially useful for discerning changes in the slope that occur between annual reviews.

3.4 How to Use the Preliminary Rating Results

This evaluation is a critical step in the RHRS process, especially where large numbers of slopes are involved. The need for further efforts is determined at this step. Initially only the "A" rated sections should be advanced for further evaluation with the detailed rating system. This will economize the effort, while insuring that it is directed toward the most critical areas. The "B" rated sections should be evaluated as time and funding allow. The "C" rated sections will receive no further attention, and therefore are not included in the statewide database.

Of the thousands of slopes addressed in Oregon, 839 received a "B" rating, while 501 received an "A" rating. All of the "A" rated slopes were further evaluated with the detailed rating system. Obviously, with that many sections identified as "A" slopes, there is enough rockfall work ahead to extend into the next century. When the "B" rated slopes are included, it is easier to understand why the "C" rated slopes are not considered significant enough to include in the database.

3.5 Workshop Problem, Classroom Exercise 1

The following figures show the site that will be used throughout the workshop for the first classroom exercise. The site is typical of a rockfall section that would be included in the rockfall database, and rated later with the detailed rating.

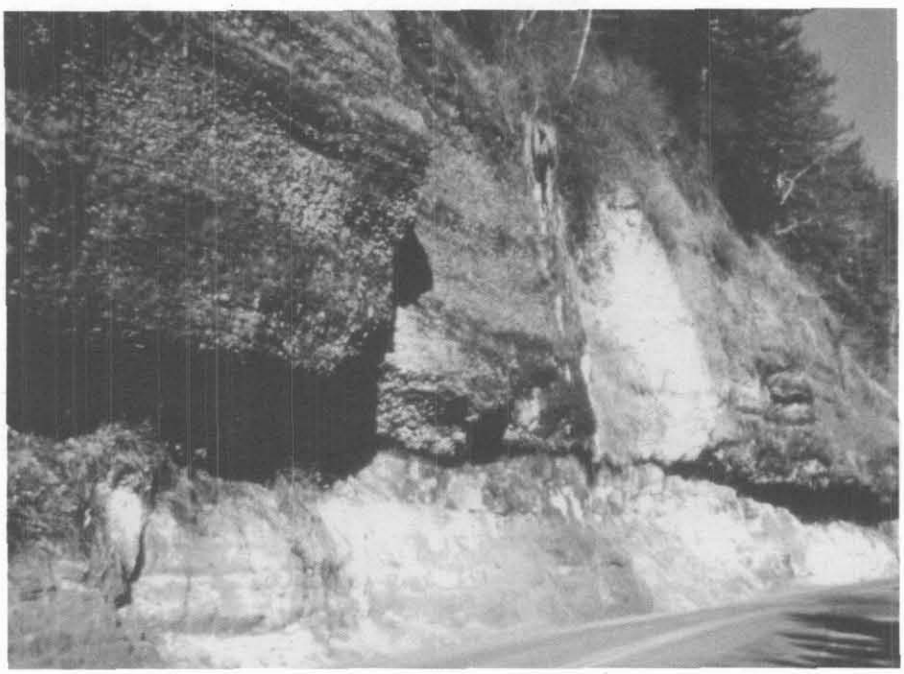


Figure 3.4 Overhanging slope caused by differential erosion.

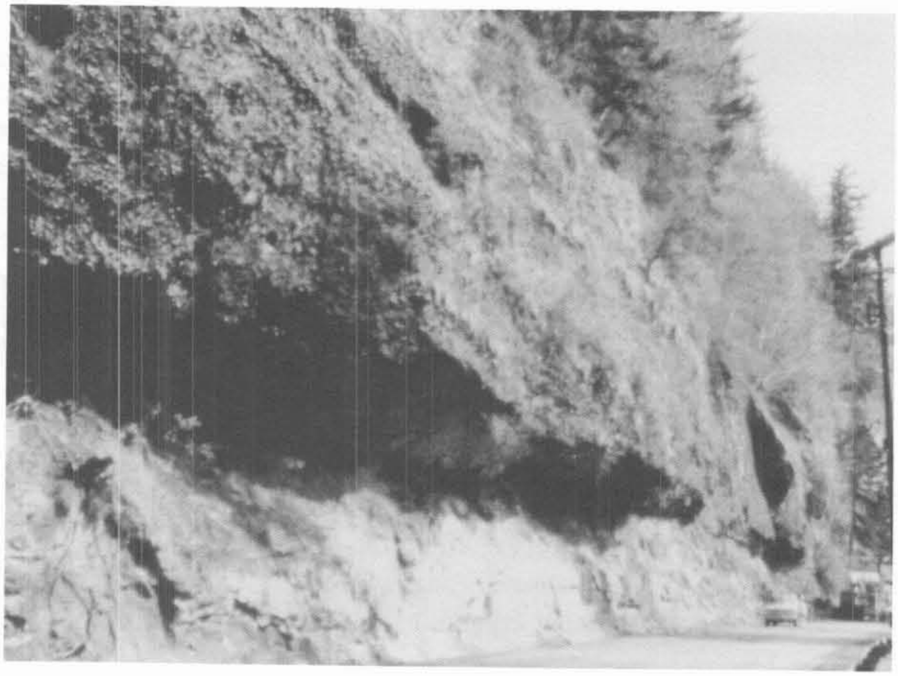


Figure 3.5 110-foot high slope.

Figure 3.6 Ineffective roadside ditch.

The slope is over 100 feet tall and it shows the severe effects of differential erosion (figure 3.5). The roadside ditch is not adequate to restrict rockfall from reaching the roadway (figure 3.6). The maintenance person states that the site is a major maintenance problem. Cobble-size rocks from the upper conglomerate unit fall on the road almost daily from November to May (rainy period) and during summer storms. In addition, about every 3 to 5 years a major rockfall event occurs, when too much of the slope becomes unsupported. Water flowing out of the slope between the two sedimentary units rapidly erodes the lower unit, resulting in the overhang.

Based on this evidence, classify the criteria in accordance with the preliminary rating system shown on page 18.

Estimated Potential for Rock on Roadway = **A B C**

Historical Rockfall Activity = **A B C**

This rockfall section would be entered into the RHRS database as

an **A B** classified slope.

CHAPTER 4: DETAILED RATING

4.1 Purpose

The purpose of the detailed rating is to numerically differentiate the risk at the identified sites. Once rated, the sites can be sorted and prioritized on the basis of their scores. These lists are then used to help make decisions on where safety projects should be initiated.

4.2 Overview

The detailed rating, shown on the next page, includes 12 categories by which slopes are evaluated and scored. (A detailed explanation of these categories is included in chapter 5.) The category scores are then totaled. Slopes with higher scores present the greater risk. These 12 categories represent the significant elements of a rockfall section that contribute to the overall hazard. The four columns of benchmark criteria to the right correspond to logical breaks in the increasing risk associated with each category.

4.3 Scoring System

Accordingly, as the risk increases from left to right, the related scores above each column increase from 3 to 81 points. These set scores increase exponentially. An exponential scoring system provides a rapid increase in score that distinguishes the more hazardous sites. The set scores are merely representatives of a continuum of points from 1 to 100. When rating a slope, using the full range of points instead of only the set points listed above each column allows the rater greater flexibility in evaluating the relative impact of conditions that are extremely variable. Initially, novice raters feel more comfortable using the set points. Less judgement is required. Continuing to use only the set points, however, is not an optimal use of the system, and is not recommended.

TABLE 4.1: SUMMARY SHEET OF THE ROCKFALL HAZARD RATING SYSTEM

CATEGORY			RATING CRITERIA AND SCORE			
			POINTS 3	POINTS 9	POINTS 27	POINTS 81
SLOPE HEIGHT			25 FEET	50 FEET	75 FEET	100 FEET
DITCH EFFECTIVENESS			Good catchment	Moderate catchment	Limited catchment	No catchment
AVERAGE VEHICLE RISK			25% of the time	50% of the time	75% of the time	100% of the time
PERCENT OF DECISION SIGHT DISTANCE			Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance 40% of low design value
ROADWAY WIDTH INCLUDING PAVED SHOULDERS			44 feet	36 feet	28 feet	20 feet
GEOLOGIC CHARACTER	CASE 1	STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		ROCK FRICTION	Rough, Irregular	Undulating	Planar	Clay infilling, or slickensided
	CASE 2	STRUCTURAL CONDITION	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features
		DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference	Extreme difference
BLOCK SIZE ——— VOLUME OF ROCKFALL/EVENT			1 Foot ——— 3 cubic yards	2 Feet ——— 6 cubic yards	3 Feet ——— 9 cubic yards	4 Feet ——— 12 cubic yards
CLIMATE AND PRESENCE OF WATER ON SLOPE			Low to moderate precipitation; no freezing periods; no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods
ROCKFALL HISTORY			Few falls	Occasional falls	Many falls	Constant falls

4.4 Scoring Aids

To assist with scoring, scoring graphs have been created for all categories, and scoring tables have been developed for all of the directly measurable categories. These scoring aids promote greater consistency in assigning scores, and increase the speed of performing the detailed rating. The graphs are useful even for the subjective categories, especially if previously rated slope conditions are plotted directly on the graphs as a reference.

4.4.1 Graphs

The graphs relate the category evaluation to an appropriate score. Even with the subjective categories, such as Ditch Effectiveness, the graphs are quite useful in assigning a score to a condition that falls somewhere between the described benchmarks. The curve on the graph is the plot of the function $y = 3^x$ which defines the exponential scoring system used for all categories. These graphs are designed to match the established criteria. If modifications to the criteria are made, the graphs must be corrected to match the new criteria.

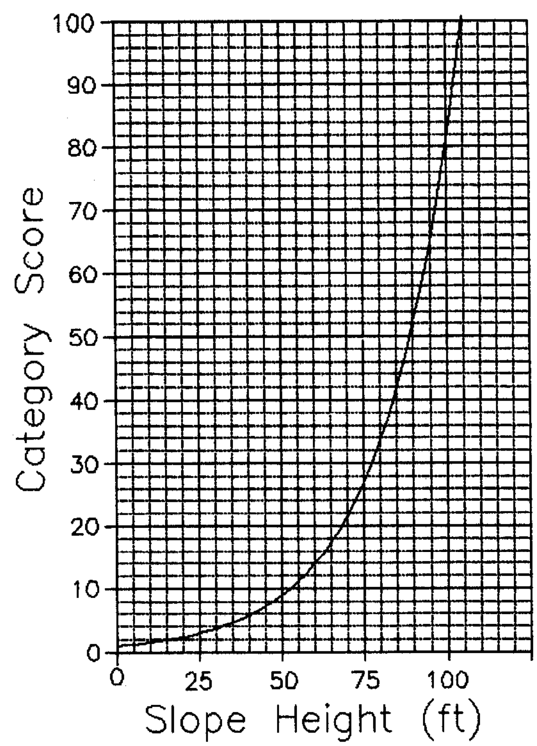
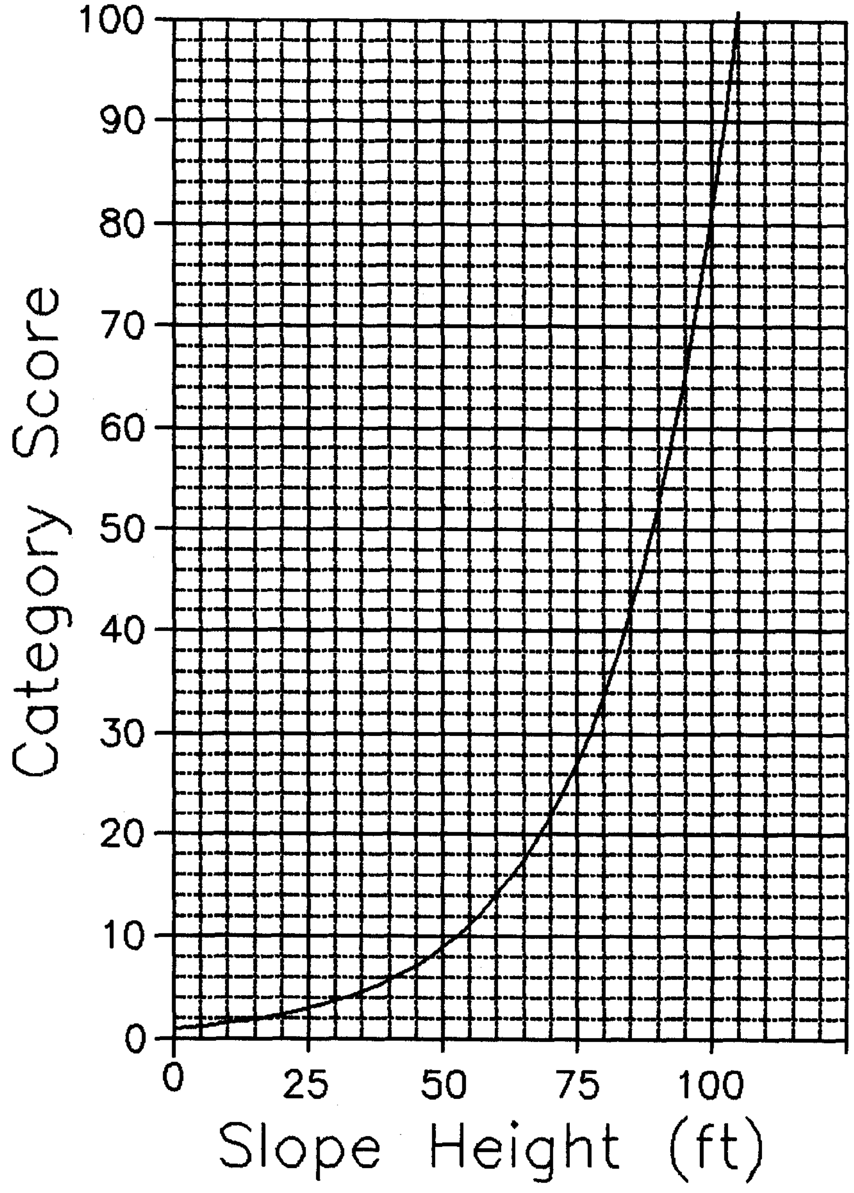


Figure 4.1 Slope height scoring graph.

The x-axis of the graph includes the criteria breaks for each category. The y-axis represents the continuum of possible points from 1 to 100. Once the category criteria for a slope have been established, the associated score can be quickly determined. See the example below:



With a measured height of 90 feet, a score of 52 points is derived.

4.4.2 Exponent Formula

Exact scores can be tabulated for the measurable categories by calculating the value of the exponent "x" of the function $y = 3^x$. The formulas that yield the exponent values are included in the table below. Some agencies may prefer to include these formulas in their database so that only the site's measurements need to be entered. Remember, these formulas will need to be modified if the rating criteria are changed.

Table 4.2 Exponent Formulas

SLOPE HEIGHT $X = \frac{\text{Slope Ht.(ft.)}}{25}$	ROADWAY WIDTH $X = \frac{52 - \text{Roadway Width (ft.)}}{8}$
AVERAGE VEHICLE RISK $X = \frac{\text{\% Time}}{25}$	BLOCK SIZE $X = \text{Block Size (ft.)}$
SIGHT DISTANCE $X = \frac{120 - \text{\% Decision Sight Dist.}}{20}$	VOLUME $X = \frac{\text{Volume (cu.ft.)}}{3}$

4.4.3 Scoring Tables

Scoring tables have been produced using these exponent formulas. Scores derived from these tables are always reproducible. The only variations possible are those due to human error or to a difference in the category measurement. The scoring tables shown on the next page, along with useful formulas used in the detailed rating, are included on the back of each field data sheet.

FEET	SLOPE HT. score	FEET	SLOPE HT. score
9	1	58	13
10	2	58	13
11	2	59	13
12	2	60	14
13	2	61	15
14	2	62	15
15	2	63	16
16	2	64	17
17	2	65	17
18	2	66	18
19	2	67	19
20	2	68	20
21	3	69	21
22	3	70	22
23	3	71	23
24	3	72	24
25	3	73	25
26	3	74	26
27	3	75	27
28	3	76	28
29	4	77	29
30	4	78	31
31	4	79	32
32	4	80	34
33	4	81	35
34	4	82	37
35	5	83	38
36	5	84	40
37	5	85	42
38	5	87	46
39	6	88	48
40	6	89	50
41	6	90	52
42	6	91	55
43	7	92	57
44	7	93	60
45	7	94	60
46	8	95	62
47	8	96	65
48	8	97	71
49	9	98	74
50	9	99	78
51	9	100	81
52	10	101	85
53	10	102	88
54	11	103	92
55	11	104	97
56	12	105	100
57	12		

Slope Height = $\frac{\sin\alpha \times \sin\beta \times X}{\sin(\alpha - \beta)}$ + H.I.

Where: H.I. = Height of Instrument

Where: X = horizontal distance between α and β

%	AVR score	%	AVR score
9	1	58	13
10	2	59	13
11	2	60	14
12	2	61	15
13	2	62	15
14	2	63	16
15	2	64	17
16	2	65	17
17	2	66	18
18	2	67	19
19	2	68	20
20	2	69	21
21	3	70	22
22	3	71	23
23	3	72	24
24	3	73	25
25	3	74	26
26	3	75	27
27	3	76	28
28	3	77	29
29	4	78	31
30	4	79	32
31	4	80	34
32	4	81	35
33	4	82	37
34	4	83	38
35	5	84	40
36	5	85	42
37	5	86	44
38	5	87	46
39	6	88	48
40	6	89	50
41	6	90	52
42	6	91	55
43	7	92	57
44	7	93	60
45	7	94	60
46	8	95	62
47	8	96	65
48	8	97	71
49	9	98	74
50	9	99	78
51	9	100	81
52	10	101	85
53	10	102	88
54	11	103	92
55	11	104	97
56	12	105	100
57	12		

%	SIGHT DIST. score	%	SIGHT DIST. score
36	100	75	12
37	96	76	11
38	90	77	11
39	86	78	10
40	81	79	10
41	77	80	9
42	.73	81	9
43	69	82	8
44	65	83	8
45	62	84	7
46	58	85	7
47	55	86	6
48	52	87	6
49	49	88	6
50	47	89	5
51	44	90	5
52	42	91	5
53	40	92	5
54	38	93	4
55	36	94	4
56	34	95	4
57	32	96	4
58	30	97	4
59	29	98	3
60	27	99	3
61	26	100	3
62	24	101	3
63	23	102	3
64	22	103	3
65	21	104	2
66	19	105	2
67	18	106	2
68	17	107	2
69	16	108	2
70	16	109	2
71	15	110	2
72	14	111	2
73	13	112	2
74	13	113	1

ROAD WIDTH IN FEET	ROAD WIDTH score
18	100
19	93
20	81
21	71
22	62
23	54
24	47
25	41
26	36
27	31
28	27
29	24
30	21
31	18
32	16
33	14
34	12
35	10
36	9
37	8
38	7
39	6
40	5
41	5
42	4
43	3
44	3
45	3
46	2
47	2
48	2
49	2
50	1

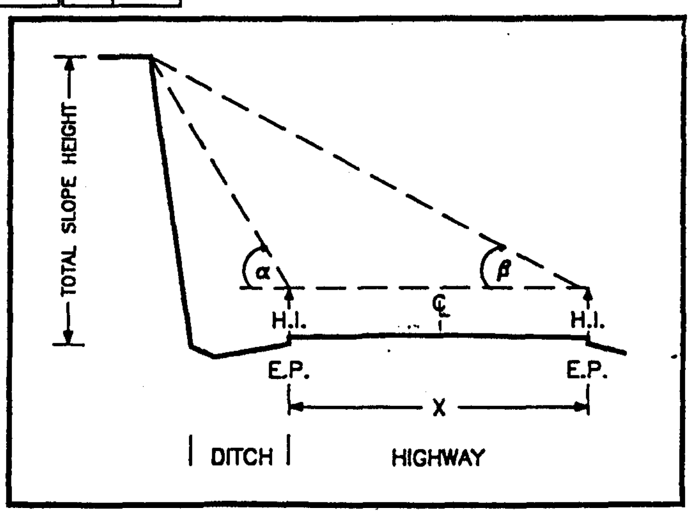
QUANTITY cu. yd.	score
1	1
1.5	2
2	2
2.5	2
3	3
3.5	4
4	4
4.5	5
5	6
5.5	7
6	9
6.5	11
7	13
7.5	16
8	19
8.5	22
9	27
9.5	32
10	39
10.5	47
11	56
11.5	67
12	81
12.5	97
13	100

Decision Sight Distance	MPH
300	20
375	25
450	30
525	35
600	40
675	45
750	50
875	55
1000	60
1015	65

BLOCK SIZE ft.	score
0.5	2
1	3
1.5	5
2	9
2.5	16
3	27
3.5	47
4	81
4.5	100

AVR% = $\frac{(\text{ADT}/24) \times \text{slope length (miles)} \times 100}{\text{speed limit}}$

Where: ADT = Average Daily Traffic



CHAPTER 5: DETAILED RATING CATEGORIES

5.1 Category Narratives

Before a decision can be made on how to score a rockfall section the criteria for each category must be well understood and carefully considered. As the RHRS evolved, it became clear that the scoring criteria needed more clarification to limit the degree to which the raters could interpret the criteria differently. To improve rating consistency, narratives were written for each category.

The narratives are based on extensive field testing of the system. Some categories require a subjective evaluation, while others can be directly measured and then scored. The narratives describe the benchmark criteria in greater detail. This description reduces the possible variation in scoring a category by limiting the amount of interpretation required by the rater.

5.2 Category Photographs

Photographs from several sites will be used as illustrations of the category criteria. The photographic examples are valuable aids for relating the criteria to actual slope conditions and, in some cases, for demonstrating the intended limits of the criteria. They will be beneficial references should you consider possible modifications to the criteria.

Classroom exercise 1, used as the preliminary rating example, will also be used throughout this chapter. This exercise will be the participants' first opportunity to apply the detailed rating to a slope. Photographs showing the condition to be rated will be included at the end of each category discussion.

5.3 Slope Height Category

This category evaluates the risk associated with the height of a slope. The height measured is the vertical height, not the slope distance. The slope height measurement is to the highest point from which rockfall is expected. If rockfall is generated from the natural slope above the cut slope, the measurement should include both the cut height and the additional vertical height on the natural slope to the rockfall source. The benchmark heights that coincide with the set points are listed below. This category is directly measured and scored.

SLOPE HEIGHT	25 ft	50 ft	75 ft	100 ft

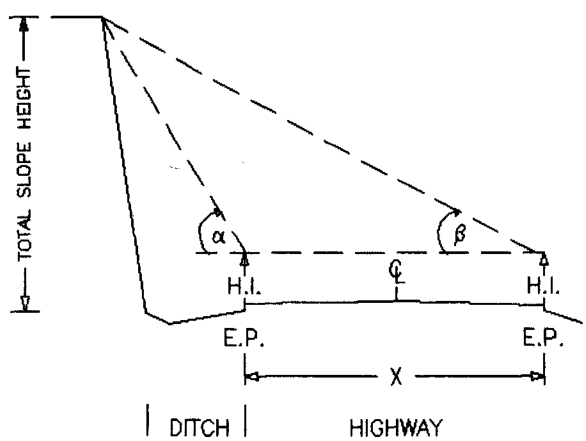
5.3.1 Category Significance

The higher a rock is located on a slope, the more potential energy it has. The increased energy potential is a greater hazard, and thus a higher rating is given as the slope height increases.

5.3.2 Method of Measurement

The slope height can be obtained by using the relationship shown below.

SLOPE HEIGHT DIAGRAM



$$\text{TOTAL SLOPE HEIGHT} = \frac{(X)\sin\alpha \cdot \sin\beta}{\sin(\alpha - \beta)} + \text{H.I.} \qquad (1)$$

Where: X = distance between angle measurements.
H.I. = height of the instrument.

The angles α and β and the distance X must be recorded. The angles can be measured with either a Brunton compass or a clinometer. Significant error can be introduced by careless measurement. Averaging several measurements of these angles should minimize this problem. To further minimize error, the elevations of the points that define the distance X should be as equal as possible. Use the edge of pavement (E.P.) designation only as a general guide. However, this measurement will also be useful in rating category 5, Roadway Width.

The highest point on a slope where rockfall is generated may not be visible from in front of the cut. This case is pictured below.

Figure 5.1 Rockfall is generated by the natural slope above the highway cut.

The slope height category is one that may need to be modified to fit local conditions. For example, in Oregon the height that initially received 81 points was 45 feet. This figure resulted in too many rockfall sections receiving a maximum slope height score. The criteria were adjusted to the present levels to provide more score separation. With the present criteria, all slopes measuring 105 feet or more in height receive a score of 100 points.

5.3.3 Criteria Examples

Figure 5.2 When the slope is nearly vertical and there is access to the top, the height can be measured with a tape.

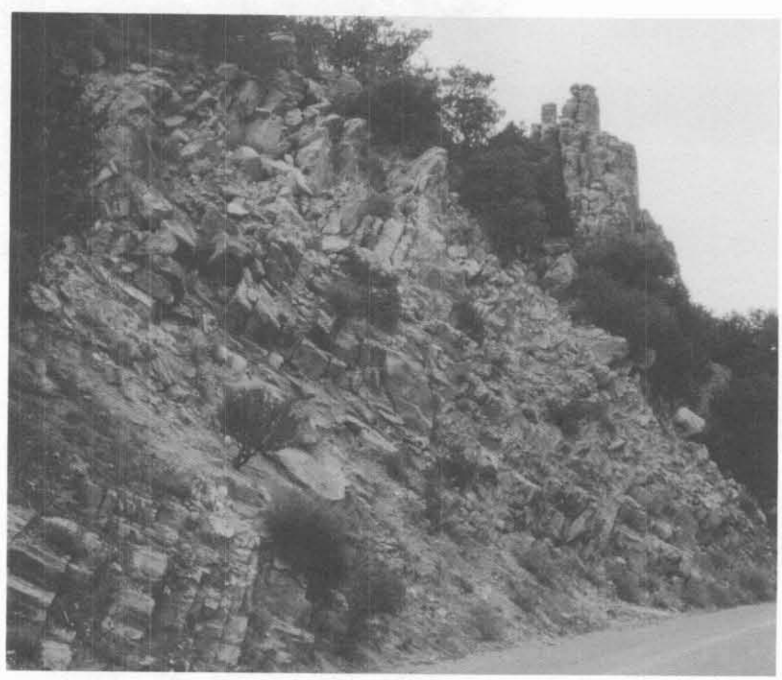


Figure 5.3 Determine the vertical height of the slope not the slope length. This 73-foot high slope is scored 25 points.

5.3.4 Classroom Exercise 1

Determine the height of the slope by using the method outlined in section 5.3.2. The measurements (and related facts) were:

1. The clinometer was held at a height of 5 feet (H.I.).
2. The X distance from edge of pavement to edge of pavement was 30 feet.
3. The α and β angles measured were 70 and 57 degrees, respectively.

Total Slope Height is ____________ feet.

Using the scoring table in section 4.4.3 (page 30), the Slope Height Category score is ______.

5.4 Ditch Effectiveness Category

The effectiveness of a ditch is measured by its ability to restrict falling rock from reaching the roadway. Many factors must be considered in evaluating this category. The reliability of the result depends heavily on the rater's experience. Ditch Effectiveness is a subjective category. The benchmark criteria are shown below.

DITCH EFFECTIVENESS	Good catchment	Moderate catchment	Limited catchment	No catchment

5.4.1 Category Significance

The risk associated with a particular rock slope section is dependent on how well the ditch is performing in capturing rockfall. When little rock reaches the roadway, no matter how much rockfall is released from the slope, the danger to the public is low and the score assessed is low. Conversely, if rockfall events are rare occurrences but the ditch is nonexistent, the resulting hazard is greater and a higher score is assigned this category.

5.4.2 Category Measurement

A wide fallout area does not necessarily guarantee that rockfall will be restricted from the highway. In estimating the ditch effectiveness, the rater should consider several factors, such as: 1) slope height and angle; 2) ditch width, depth and shape; 3) anticipated volume of rockfall per event; and 4) impact of slope irregularities (launching features) on falling rocks. Evaluating the effect of slope irregularities is especially important because they can completely negate the benefits expected from a fallout area. Valuable information on ditch performance can be obtained from maintenance personnel.

5.4.3 Criteria Narratives

Scoring should be consistent with the following criteria descriptions.

3 points	Good Catchment All or nearly all falling rocks are retained in the catch ditch.
9 points	Moderate Catchment Falling rocks occasionally reach the roadway.
27 points	Limited Catchment Falling rocks frequently reach the roadway.
81 points	No Catchment No ditch, or ditch is totally ineffective. All or nearly all falling rocks reach the road.

5.4.4 Criteria Examples

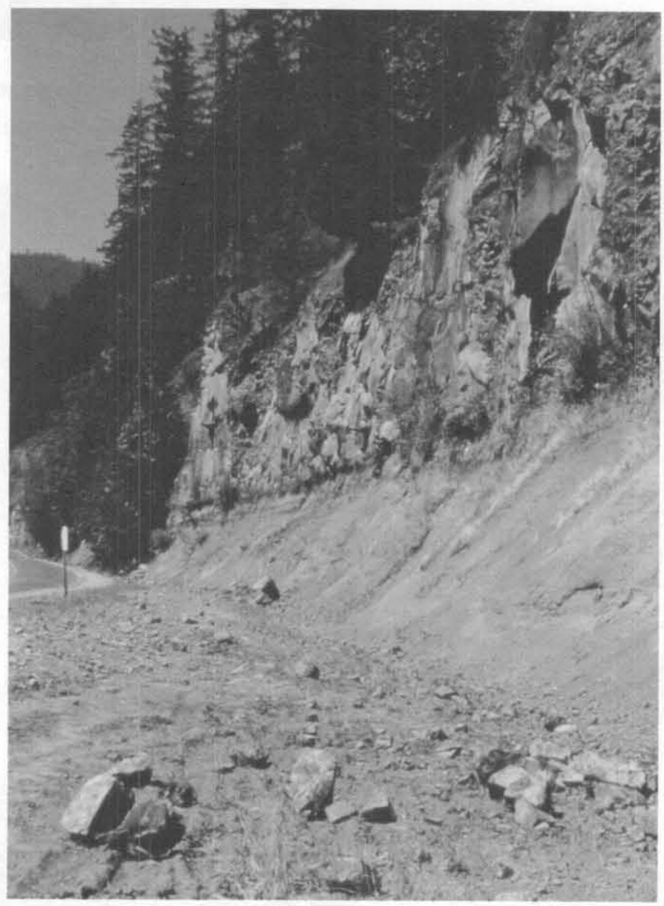


Figure 5.4 The width of this fallout area provides good catchment.

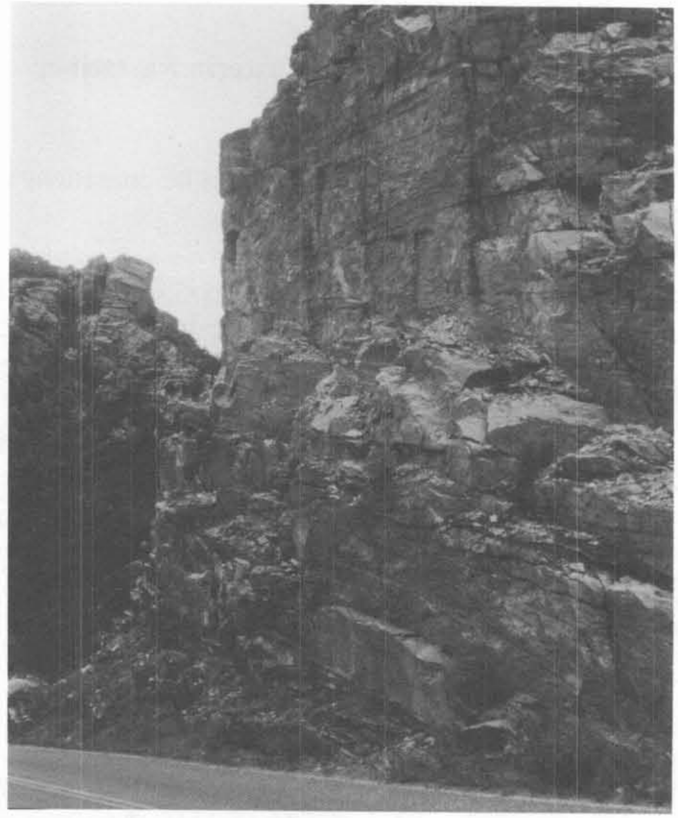


Figure 5.5 The launch feature midway up the slope adds to the ineffectiveness of this narrow roadside ditch.

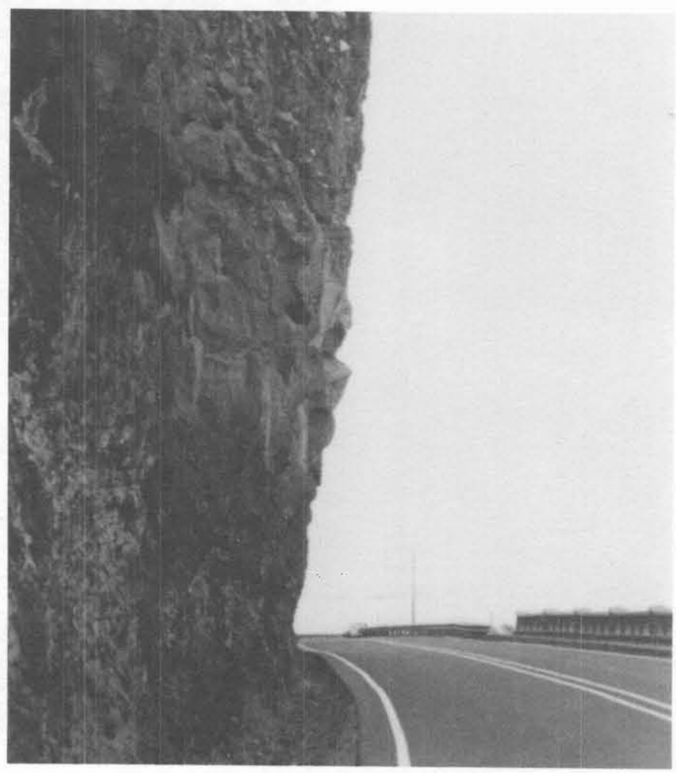


Figure 5.6 Rockfall from this slope will land on the roadway. No catchment is provided by the ditch.

5.4.5 Classroom Exercise 1

The small size of the ditch and the overhanging slope, shown in figure 5.7, combine to make this an almost totally ineffective ditch. Most of the rocks that fall at this site reach the roadway.

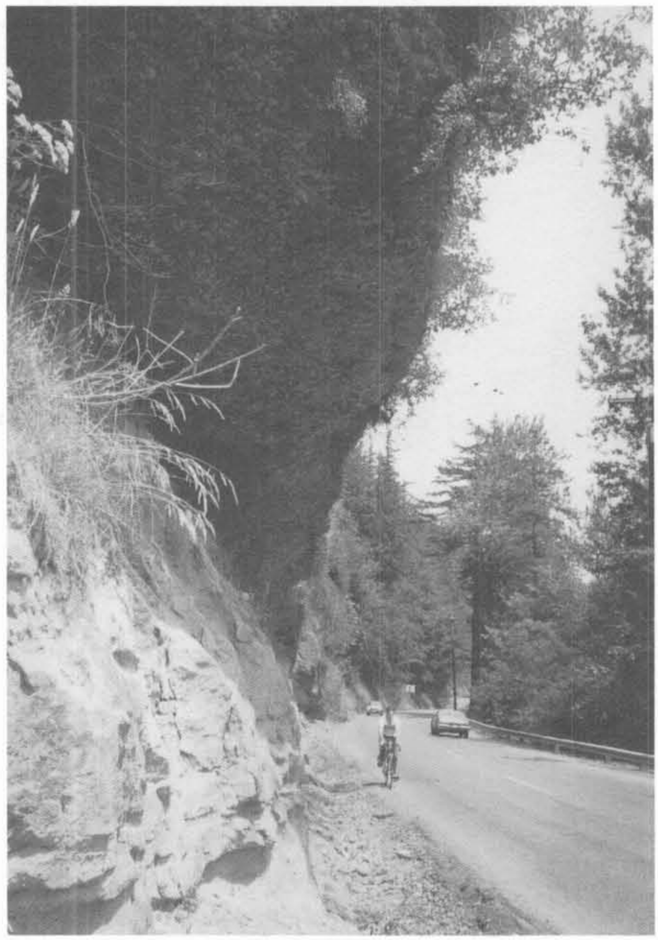


Figure 5.7 The large volume events possible at this site would not be retained in the ditch.

On the basis of the criteria provided in Section 5.4.3, an appropriate Ditch Effectiveness Category score is ______.

5.5 Average Vehicle Risk (AVR) Category

With the AVR category, the risk associated with the percentage of time a vehicle is present in the rockfall section is evaluated. The percentage is obtained by using the formula (shown below) based on slope length, average daily traffic (ADT), and the posted speed limit at the site.

$$\frac{\text{ADT (cars/day) X Slope Length (miles) / 24 (hours/day)}}{\text{Posted Speed Limit (miles/hour)}} \text{ X } 100\% = \text{AVR}$$

The results are rated based on the established benchmark criteria.

AVERAGE VEHICLE RISK (AVR)	25% of the time	50% of the time	75% of the time	100% of the time

5.5.1 Category Significance

Combining the ADT, the length of the rockfall section and the posted speed limit produces a category that represents the potential for a vehicle to be involved in a rockfall event. The average percent of time a vehicle is present within the rockfall section is calculated. Another way of looking at this is that it shows how many vehicles are in the rockfall section at any one time. A rating of 100% means that on the average a vehicle will be within the defined rockfall section 100% of the time. Where high ADT's or longer slope lengths exist, values greater than 100% will result. When this occurs, it means that at any particular time, more than one vehicle is present within the measured section. The result approximates the likelihood of vehicles being present and thus involved in a rockfall incident. The result also reflects the significance of the route.

5.5.2 Criteria Example

Figure 5.8 Roadway curves with reduced posted speed limits are common in rugged terrain. Remember to record this information.

5.5.3 Classroom Exercise 1

This rockfall site extends from Mile Point 4.06 to Mile Point 4.48. The ADT is 3,000 cars a day. While at the site, the rater remembered to record the posted speed limit which was 40 miles per hour. Using the following formula discussed in section 5.5, calculate the AVR.

$$\frac{\text{ADT (cars/day) X Slope Length (miles) / 24 (hours/day)}}{\text{Posted Speed Limit (miles/hour)}} \text{ X } 100\% = \text{AVR}$$

AVR = ________

Refer to the appropriate scoring table to determine the AVR score.

Score = ________

5.6 Percent of Decision Sight Distance Category

The Decision Sight Distance category compares the amount of sight distance available through a rockfall section to the low design amount prescribed by AASHTO. Sight distance is the shortest distance that a six-inch object is continuously visible to a driver along a roadway. Decision sight distance (DSD) is the length of roadway, in feet, required by a driver to perceive a problem and then bring a vehicle to a stop.

PERCENT OF DECISION SIGHT DISTANCE	Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance, 40% of low design value

5.6.1 Category Significance

The DSD is critical when obstacles on the road are difficult to see, or when unexpected or unusual maneuvers are required. Throughout a rockfall section the sight distance can change appreciably. Horizontal and vertical highway curves along with obstructions such as rock outcrops and roadside vegetation can severely limit a driver's ability to notice and react to a rock in the road.

5.6.2 Method of Measurement

First, record the posted speed limit throughout the rockfall section. Then drive through the site from both directions to determine where the sight distance is most restricted. Decide which direction has the shortest line of sight. Both horizontal and vertical sight distances should be evaluated. Normally an object will be most obscured when it is located just beyond the sharpest part of a curve. Place a six-inch object in that position on the fogline or on the edge of pavement if there is no fogline. Then walk along the fogline (edge of pavement) in the opposite direction to the traffic flow, measuring the distance it takes for the object to disappear at an eye height of 3.5 ft above the road surface. A roller tape is helpful for making this measurement.

5.6.3 AASHTO Decision Sight Distances

The required decision sight distance, based on the posted speed limit can be determined from the table below.

Table 5.1 Decision Sight Distance

Posted Speed Limit (mph)	Decision Sight Distance (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1,000
65	1,050

The relationships between decision sight distance and the posted speed limit were modified from table III-3 of AASHTO's "Policy on Geometric Design of Highways and Streets" (4). The distances listed represent the low design value. The posted speed limit throughout the rockfall section should be used instead of the highway design speed.

5.6.4 DSD Formula

Once the actual sight distance is measured and the recommended sight distance determined from the table, the two values can be substituted into the following formula to calculate the "Percent of Decision Sight Distance."

$$\frac{\text{Actual Sight Distance}}{\text{Decision Sight Distance}} \times 100\% = \_\_\_\_\ \%$$

5.6.5 Criteria Examples

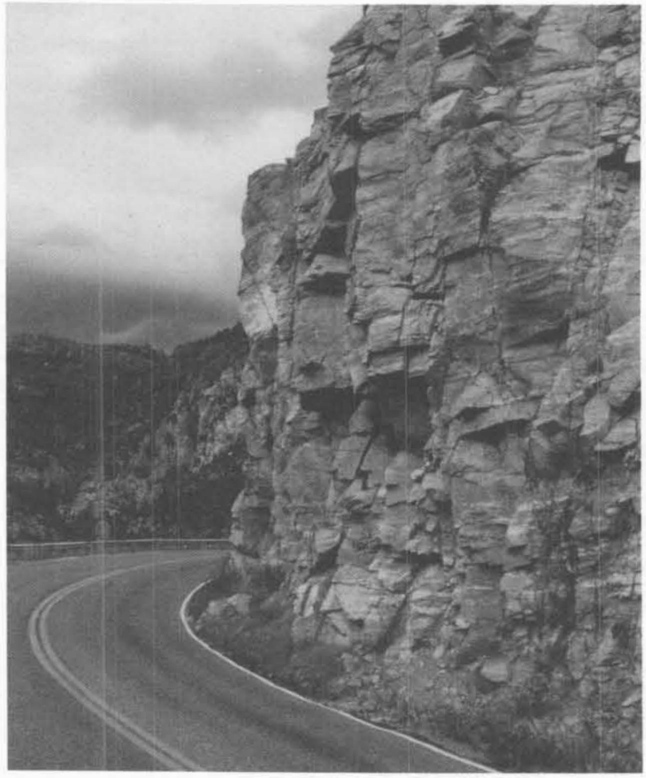


Figure 5.9 Example of a horizontal curve that could hide a rock in the road ahead.

Figure 5.10 Vertical curves can also restrict sight distance.

5.6.6 Classroom Exercise 1

The sight distance approaching from the west is quite good. However, as you can see in figure 5.11, the sight distance from the east end of the rockfall section is impaired by the horizontal highway curve.

Figure 5.11 The measured sight distance is 330 feet.

Based on the posted speed limit of 40 miles per hour, determine the appropriate DSD from table 5.1. Substitute the two values into the following formula to calculate the percent of decision sight distance.

$$\frac{\text{Actual Sight Distance}}{\text{Decision Sight Distance}} \times 100\% = \_\_\_\_\_\_ \%$$

Using the DSD scoring table, determine the score for this category.

DSD Score = ______

5.7 Roadway Width Category

The roadway width is measured perpendicular to the highway. The minimum width throughout the rockfall section is used when the roadway width is not constant. The unpaved shoulder adjacent to the roadway is not included in the measurement. The benchmark criteria are:

ROADWAY WIDTH INCLUDING PAVED SHOULDERS	44 feet	36 feet	28 feet	20 feet

5.7.1 Category Significance

If a driver notices rocks in the road, or rocks falling, it is possible for the driver to react and take evasive action to avoid them. The more room there is for this maneuver, the greater the likelihood the driver will successfully miss the rock without hitting some other roadside hazard or oncoming vehicle. The measurement represents the available maneuvering width of the roadway.

5.7.2 Method of Measurement

The roadway width is measured perpendicular to the highway centerline. The edges of pavement define the roadway. It is difficult to get uniform estimates among different raters about what is unpaved shoulder and what is unmaneuverable side slope. For that reason, the unpaved shoulders are not included in the measurement. When the roadway width varies throughout the rockfall section, the section measured should be the area of minimum width. On divided roadways, only the portion available to the driver is measured.

5.7.3 Criteria Examples

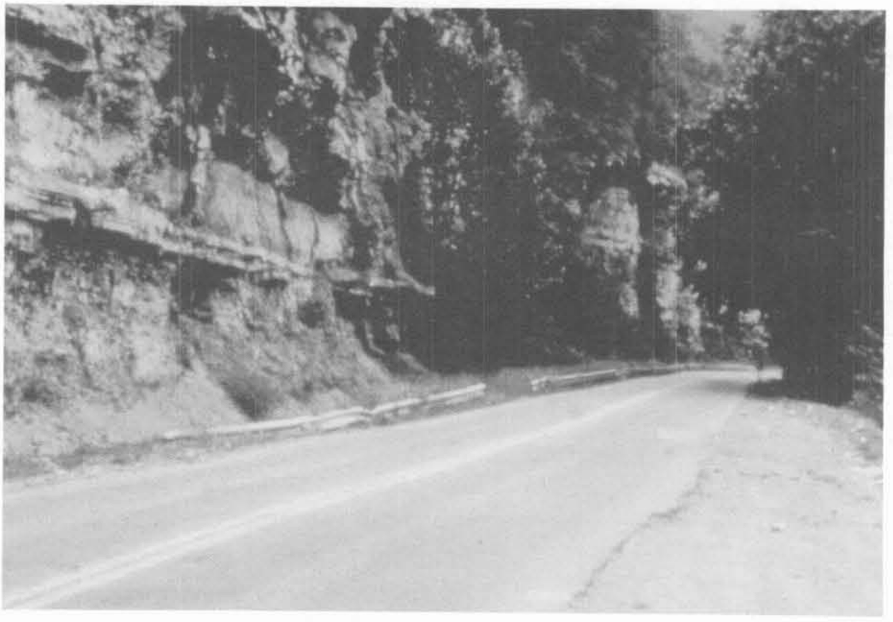


Figure 5.12 Only the width of the paved surface is rated. Note the loss of the unpaved shoulder in the distance.

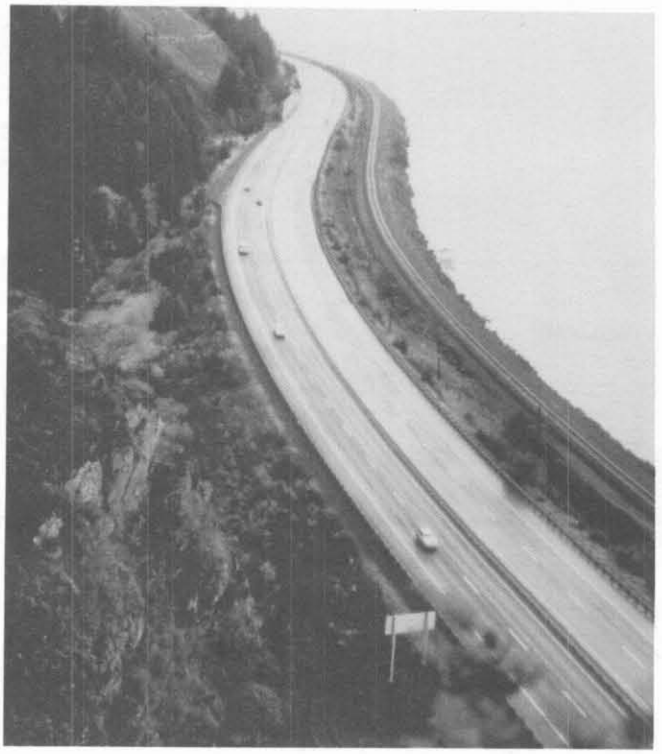


Figure 5.13 On divided highways, only the portion available to the driver is measured.

5.7.4 Classroom Exercise 1

The road through this section consists of two 12-foot travel lanes, a 4-foot paved shoulder on the south side of the road, and a 2-foot paved shoulder on the north side near the slope. According to the appropriate scoring table, what is the Roadway Width Category score for this site?

Roadway Width Score = _______

5.8 Geologic Character

The geologic conditions of the rockfall section are evaluated with these categories. Since the conditions that cause rockfall generally fit into 2 categories, Case One and Case Two rating criteria have been developed. Case One is for slopes where joints, bedding planes, or other discontinuities, are the dominant structural features that lead to rockfall. Case Two is for slopes where differential erosion or oversteepening is the dominant condition that controls rockfall.

Whichever case best fits the slope should be used for the rating. If both situations are present, and it is unclear which dominates, both are scored, but only the worst case (highest score) is used in the rating. The criteria for the two cases are shown below.

GEOLOGIC CHARACTER	CASE 1	STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		ROCK FRICTION	Rough, Irregular	Undulating	Planar	Clay infilling, or slickensided
	CASE 2	STRUCTURAL CONDITION	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
		DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference, favorable structure	Large difference, unfavorable structures

5.8.1 Case One, Structural Condition Category

Rockfall from Case One slopes occurs as a result of movement along discontinuities. The word "joint" as applied here, represents all possible types of discontinuities, including bedding planes, foliations, fractures, and faults. The term "continuous" refers to joints that are greater than 10 feet in length. The term "adverse" applies not only to the joint's spatial relationship to the slope, but also to such things as rock friction angle, joint filling, and the effects of water, if present.

Following are the benchmark criteria for the Case One, Structural Condition Category.

STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation

5.8.1.1 Category Significance

Jointed rock is much more prone to rockfall than is massive rock. Movement occurs along these joints where the resistance to movement is significantly less than the intact strength of the rock itself. When the joints are oriented adversely to the slope, the potential for rockfall is greater. Adverse joints are those that singularly or in combination with other joints make planar, circular, block, wedge or toppling failures kinematically possible. The following diagram shows an adverse condition.

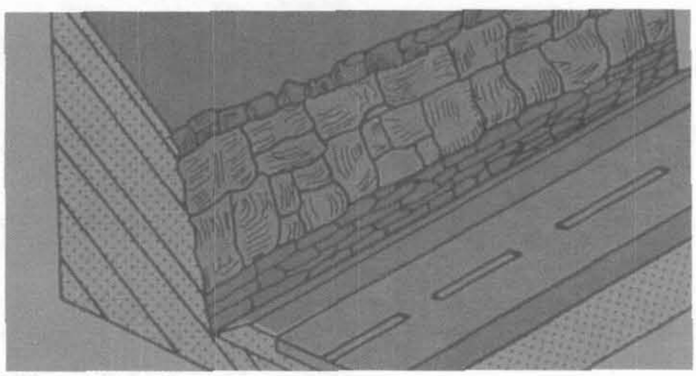


Figure 5.14 The bedding is dipping toward the highway.

5.8.1.2 Criteria Narratives

Scoring should be consistent with the following criteria descriptions.

3 points — Discontinuous Joints, Favorable Orientation Slope contains jointed rock with no adversely oriented joints.

9 points — Discontinuous Joints, Random Orientation Slope contains randomly oriented joints creating a variable pattern. The slope is likely to have some scattered blocks with adversely oriented joints, but no dominant adverse pattern is present.

27 points — Discontinuous Joints, Adverse Orientation Rock slope exhibits a prominent joint pattern with an adverse orientation. These features have less than 10 feet of continuous length.

81 points — Continuous Joints, Adverse Orientation Rock slope exhibits a dominant joint pattern with an adverse orientation and a length greater than 10 feet.

5.8.1.3 Criteria Examples

Figure 5.15 Randomly jointed rock.

Figure 5.16 Note the toppling failures. This, too, is an adverse joint condition.

Figure 5.17 Continuous joints with adverse orientation.

5.8.2 Case One, Rock Friction Category

The potential for rockfall by movement along discontinuities is controlled by the condition of the joints. The condition of the joints is described in terms of micro and macro roughness. The roughness is rated on the basis of the following criteria.

ROCK FRICTION	Rough, Irregular	Undulating	Planar	Clay infilling or slickensided

5.8.2.1 Category Significance

This parameter directly affects the potential for a block to move relative to another. Friction along a joint, bedding plane, or other discontinuity is governed by the macro and micro roughness of the surfaces. Macro roughness is the degree of undulation of the joint relative to the direction of possible movement. Micro roughness is the texture of the surface. On slopes where the joints contain hydrothermally altered or weathered material, movement has occurred causing slickensides or fault gouge to form, or the joints are open or filled with water, the rockfall potential is greater.

5.8.2.2 Criteria Narratives

Following are the benchmark criteria descriptions.

3 points — <u>Rough, Irregular</u> The surface of the joints are rough and the joint planes are irregular enough to cause interlocking.

9 points — <u>Undulating</u> Macro rough but without the interlocking ability.

27 points — <u>Planar</u> Macro smooth and micro rough joint surfaces. Friction is derived strictly from the roughness of the rock surface.

81 points — <u>Clay Infilling, or Slickensides</u> Low friction materials separate the rock surfaces, negating any micro or macro roughness of the joint surfaces. Slickensided joints also have a lower friction angle, and belong in this category.

5.8.2.3 Criteria Examples

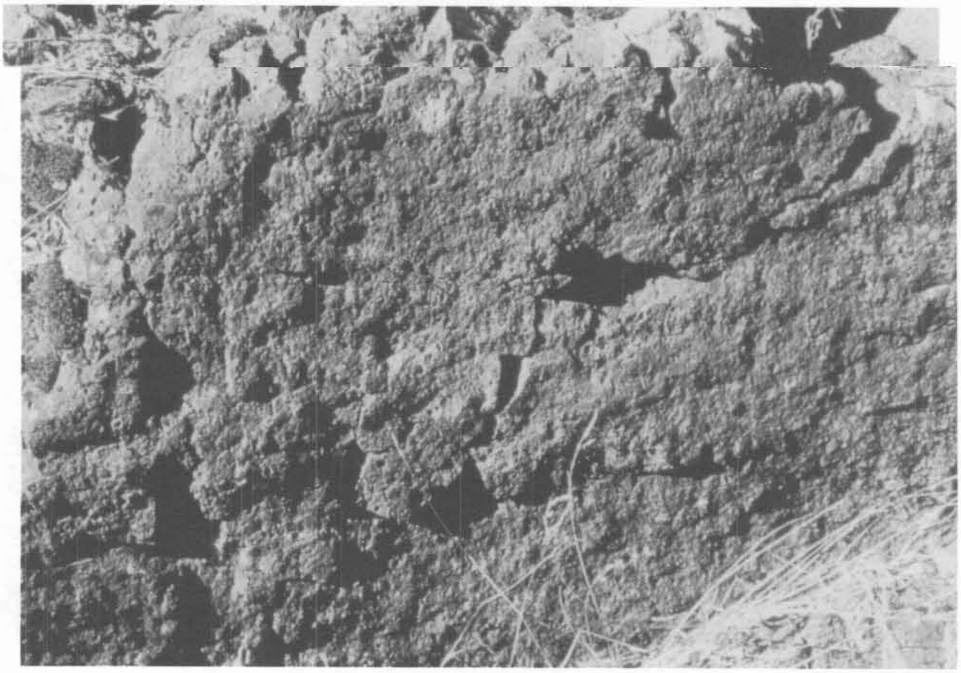


Figure 5.18 An irregular joint. Note the rough texture of the exposed surface.

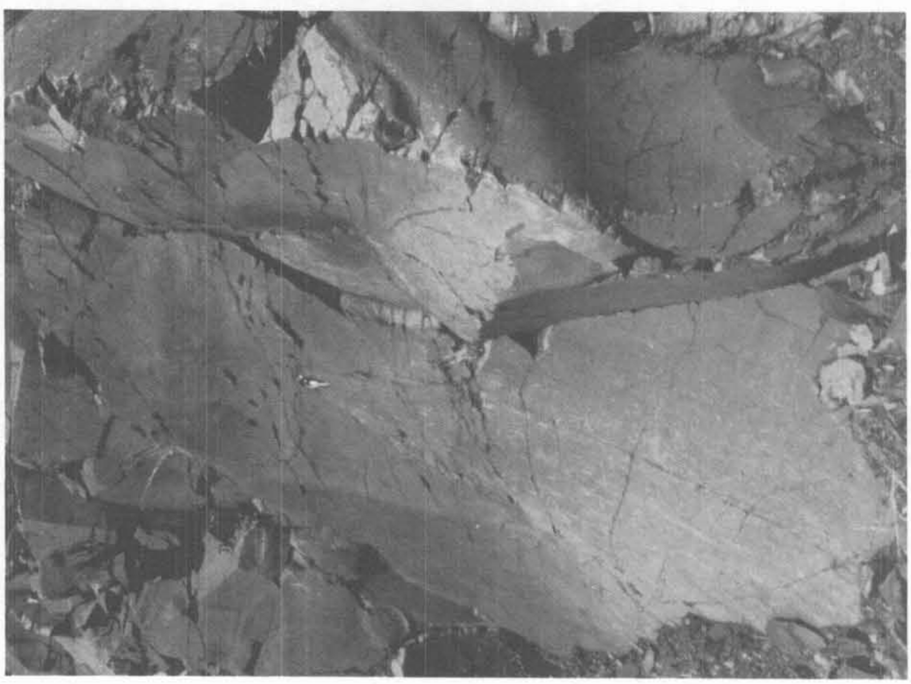


Figure 5.19 Exposed undulating joint surface.

Figure 5.20 A planar joint surface. The surface is macro smooth.

Figure 5.21 Weathered joint surface. Note the red colored clay between the rock surfaces.

5.8.3 Case Two, Structural Condition Category

This case is used for slopes where differential erosion or oversteepening is the dominant condition that leads to rockfall. Erosion features include oversteepened slopes, unsupported rock units (overhangs), or exposed resistant rocks on a slope, which may eventually lead to a rockfall event. The benchmark criteria are:

STRUCTURAL CONDITION	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features

5.8.3.1 Category Significance

Rockfall is commonly caused by erosion that leads to a loss of support either locally or throughout a slope. The types of slopes that may be susceptible to this condition are: layered units containing more easily erodible units that undermine more durable rock; talus slopes; highly variable units, such as conglomerates, and mudflows, that weather differentially, allowing resistant rocks and blocks to fall; and rock/soil slopes that weather allowing rocks to fall as the soil matrix material is eroded.

5.8.3.2 Criteria Narratives

Scoring should be consistent with the following criteria descriptions.

3 points <u>Few Differential Erosion Features</u> Minor differential erosion features that are not distributed throughout the slope.

9 points <u>Occasional Erosion Features</u> Minor differential erosion features that are widely distributed throughout the slope.

27 points <u>Many Erosion Features</u> Differential erosion features that are large and numerous throughout the slope.

81 points <u>Major Erosion Features</u> Severe cases such as dangerous erosion-created overhangs, or significantly oversteepened soil/rock slopes or talus slopes.

5.8.3.3 Criteria Examples

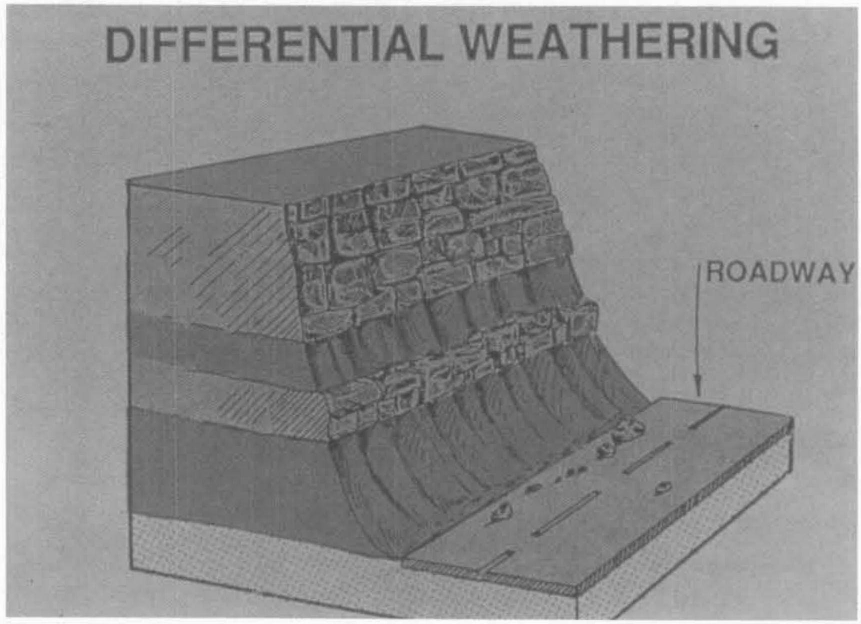


Figure 5.22 Rockfall caused by differential erosion.

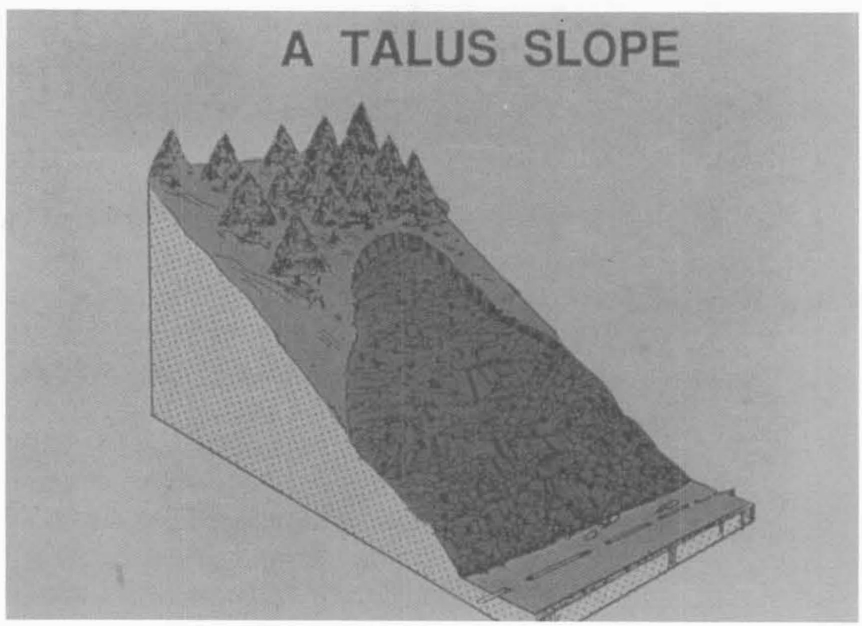


Figure 5.23 Movement of material on an active talus slope is a Case Two condition.

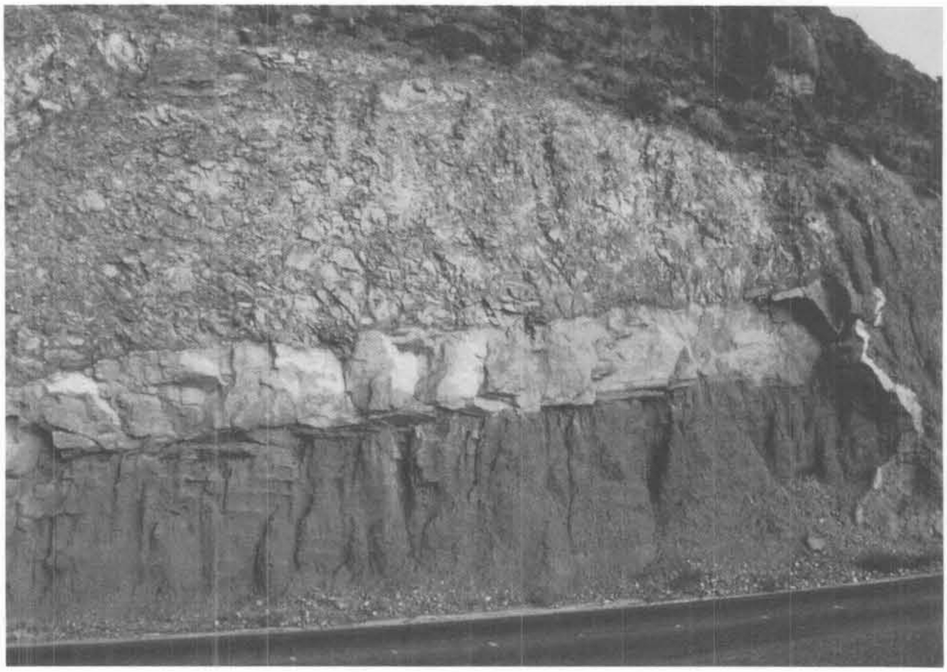


Figure 5.24 Layered material can be susceptible to differential erosion.

Figure 5.25 Oversteepened soil/rock slope

5.8.4 Case Two, Difference in Erosion Rates Category

The materials comprised in a slope can have markedly different characteristics that control how rapidly weathering and erosion occur. As erosion progresses, resulting in portions of the slope becoming unsupported, the likelihood of a rockfall event increases. The benchmark criteria listed below relate to the difference in erosion rates within a slope and how they affect the risk of rockfall.

DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference, favorable structure	Large difference, unfavorable structure

5.8.4.1 Category Significance

The rate of erosion on a Case Two slope directly relates to the potential for a future rockfall event. As erosion progresses, unsupported or oversteepened slope conditions develop. The impact of the common physical and chemical erosion processes, as well as the effects of man's actions, should be considered. The degree of hazard caused by erosion and thus the score given this category, should reflect the rate at which erosion is occurring; the size of rocks, blocks, or units being exposed; the frequency of rockfall events; and the amount of material released during an event.

5.8.4.2 Criteria Narratives

Scoring should be consistent with the following criteria descriptions.

3 points — Small Difference Erosion features take many years to develop. Slopes that are near equilibrium with their environment are covered by this category.

9 points — Moderate Difference The difference in erosion rates allows erosion features to develop over a period of a few years.

27 points	Large Difference The difference in erosion rates allows noticeable changes in the slope to develop annually.
81 points	Extreme Difference The difference in erosion rates allows rapid and continuous development of erosion features.

5.8.4.3 Criteria Examples

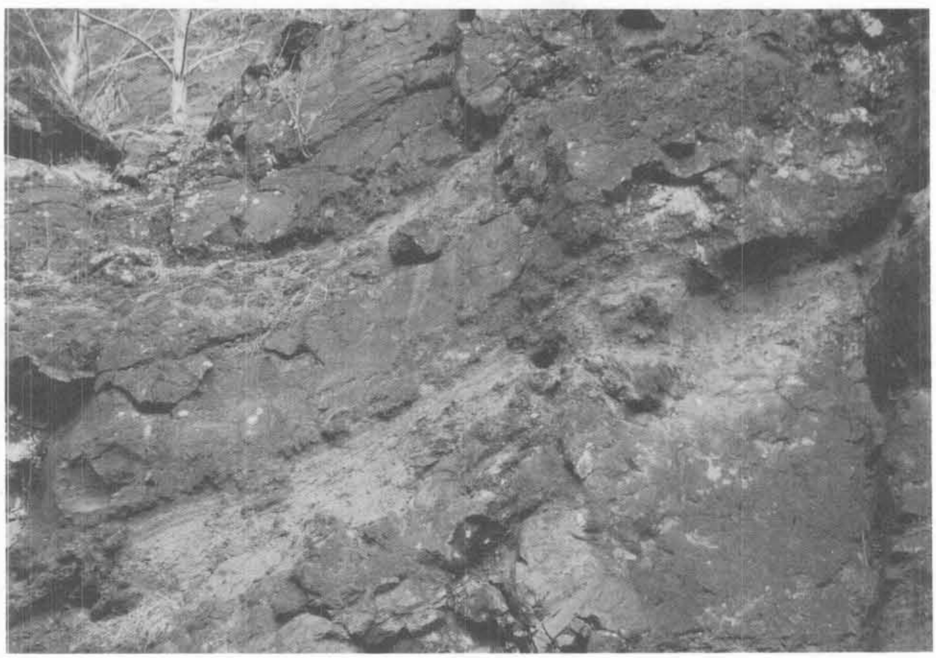


Figure 5.26 The soil in the joints is more susceptible to erosion than the resistant rock. The difference is large.

Figure 5.27 The cinders at the base of the slope are strongly affected by freeze/thaw cycles and rain. The difference is extreme.

5.8.5 Selecting The Proper Case

A background in engineering geology, or additional training in this field, is very beneficial in making this type of evaluation. Rating the geologic character as it relates to rockfall potential draws heavily on the expertise of the rater. Many hours were dedicated to developing this category and refining the narrative. The narrative for this section required a delicate balance between giving the raters enough guidance and allowing them enough freedom to use their expertise and judgement.

The selection of a case to be rated should be based on the physical cause of rockfall. The choice will generally be fairly clear. For example, if rockfall occurs through slippage of rock against rock along a discontinuity, then Case One should be used. If the rockfall is due to undermining or over steepening leading to loss of support, then Case Two should be used.

If both situations are present, both are scored but only the worst case (highest total Case One or Case Two score) is used in determining the rating. If a localized area is causing a serious rockfall problem, the overall length of the slope being rated should be reduced, and the problem area should be rated separately.

5.8.6 Classroom Exercise 1

The upper portion of the slope is a conglomerate unit with hard quartzite and igneous rock cobbles suspended in a cemented sand matrix. About 10 to 15 feet from the base of the slope is a near horizontal contact between the conglomerate unit and a poorly cemented siltstone unit. Water flows from the slope year round at the contact between the two units.

Two types of rockfall occur at this site, both caused by the same geologic process - differential erosion. The difference in erosion rates between the conglomerate and the siltstone units is significant. The water daylighting in the slope at the contact between these units accelerates the erosion of the siltstone creating dangerous overhangs. The size of the overhang increases by several inches per year, until the overhanging material breaks off in a major rockfall event. The failures occur along vertical stress relief joints that form in the conglomerate unit parallel to the slope face. These are the major events that the maintenance person described as happening approximately every 3 to 5 years. While this process is taking place, the abundant rain and wind at the site erodes the matrix material of the conglomerate causing the cobbles to fall on a regular basis.

The historic information combined with the knowledge of how the geologic processes result in the rockfall events, leads to the conclusion that this is a Case Two slope.

Using the above information and the narratives for the benchmark criteria found on pages 55 and 58, assign a score for the two categories under Geologic Character, Case Two.

Structural Condition Score = __________

Difference in Erosion Rates Score = __________

5.9 Block Size or Volume of Rockfall Per Event Category

In some rockfall events, the failure is comprised of an individual block. In others cases, the event may include many blocks of differing sizes. Which ever type of event is typical is rated according to the following category benchmarks.

BLOCK SIZE	1 ft	2 ft	3 ft	4 ft
QUANTITY OF ROCKFALL/EVENT	3 cubic yards	6 cubic yards	9 cubic yards	12 cubic yards

5.9.1 Category Significance

Larger blocks or volumes of falling rock produce more total kinetic energy and greater impact force than smaller events. In addition, the larger events obstruct more of the roadway reducing the possibility of safely avoiding the rock(s). In either case, the larger the blocks or volume the greater the hazard created and thus the higher the assigned score.

5.9.2 Which Criterion to Use

This measurement should be representative of the type of rockfall event most likely to occur. If individual blocks are typical of the rockfall, block size should be used for scoring. If a mass of blocks tends to be the dominant type of rockfall, volume per event should be used. A decision on which to use can be determined from the maintenance history, or estimated from observed conditions when no history is available. This measurement will also be beneficial in determining remedial measures.

5.9.3 Criteria Examples

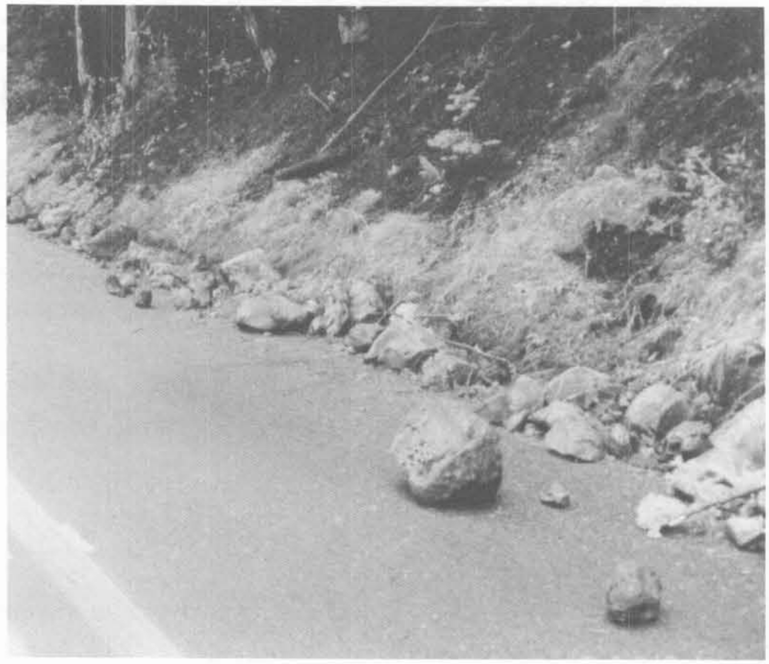


Figure 5.28 Block size used to rate this event.

10-30-85 The Oregonian/BILL MURPHY

ROCKSLIDE — A battered truck tractor rests against a massive boulder that fell as the log truck was traveling along Washington 14 east of Stevenson, Wash., early Wednesday morning. The driver of the truck suffered a broken ankle and other minor injuries in the accident.

2nd rockslide blocks Washington route

By ROLLA J. CRICK
of The Oregonian staff

STEVENSON, Wash. — A massive rockslide that included a single boulder larger than a one-story

"I guess I'm lucky to be alive," said Clifford R. Nickols, 41, of Woodland, Wash., whose three-axle log truck and trailer struck the first slide.

The slide's location is across the Columbia River

of the Gods on the west and the Hood River-Bingen bridge on the east.

The truck's trailer and several large rocks went across the two-lane highway and onto the adjacent

Figure 5.29 Either block size or volume could be used here to obtain a maximum score.

5.9.4 Classroom Exercise 1

During the preliminary rating, the maintenance person explained that this site has two different types of rockfall, both of which occur on a regular basis. One type consists mostly of 3-to-5-inch cobbles that erode out of the conglomerate unit. Occasionally, portions of the conglomerate up to about 3 feet in diameter break off. The second type of rockfall occurs when the large overhang becomes unstable, and a large volume of rock falls off at one time. The volume of these singular events usually exceeds 50 cubic yards of material on the road.

Using the scoring tables, rate the two types of rockfall that occur at the site, and determine which score to use for rating this category.

Block Size Score = ________

Quantity of Rockfall/Event Score = _______

Score for this category = __________

5.10 Climate and Presence of Water on Slope Category

The effects of precipitation, freeze/thaw cycles, and water flowing on the slope are evaluated with this category according to the following benchmark criteria.

CLIMATE AND PRESENCE OF WATER ON SLOPE	Low to moderate precipitation; no freezing periods; no water on slope	Moderate precipitation or short freezing periods; or intermittent water on slope	High precipitation or long freezing periods; or continual water on slope	High precipitation and long freezing periods; or continual water on slope and long freezing periods

To assure proper score separation, the criteria for this category should be adjusted to fit local conditions.

5.10.1 Category Significance

Water and freeze/thaw cycles both contribute to the weathering and movement of rock materials and a reduction in overall slope stability. This category evaluates the amount of precipitation and duration of freezing periods, because these are measurable quantities that are directly related to features that cause rockfall. In addition, water flowing on a slope promotes erosion and thus is also considered in this category.

5.10.2 Method of Evaluation

If water is known to flow continually or intermittently from the slope, it is rated accordingly. Areas receiving less than 20 inches per year are "low precipitation areas." Areas receiving more than 50 inches per year are considered "high precipitation areas." The impact of freeze/thaw cycles can be estimated from knowledge of freezing conditions and their effects at the site.

The rater should note that the 27-point category is for sites with long freezing periods *or* water problems such as high precipitation or continually flowing water. The 81-point category is reserved for sites that have *both* long freezing periods and one of the two extreme water conditions.

5.10.3 Information Source

Information on average temperatures and length of freezing periods can be obtained from National Oceanic and Atmospheric Administration (NOAA) climatological publications (5). An agency-wide precipitation map is a useful scoring aid. This information is usually available from routinely maintained, state-wide rain gauge data.

5.10.4 Criteria Example

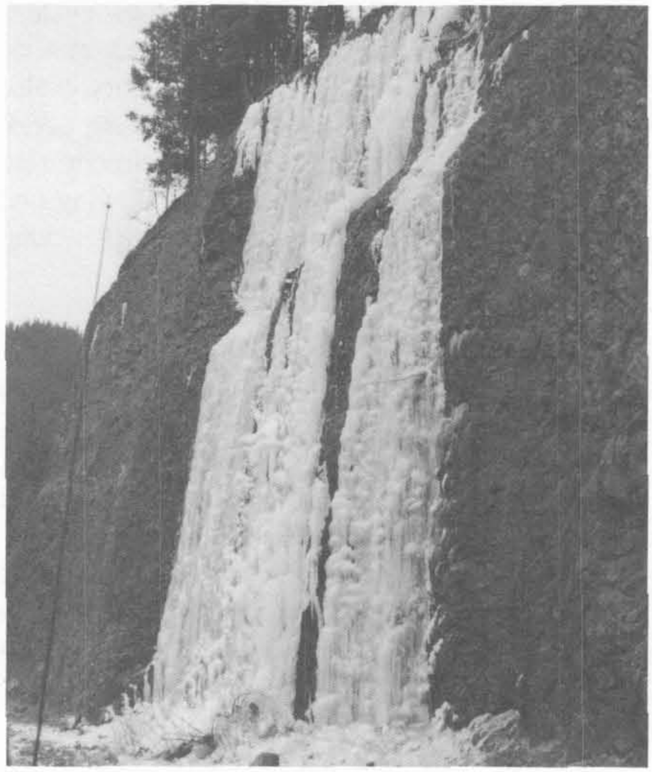


Figure 5.30 Both climate and excess water on the slope will eventually cause problems at this newly constructed site.

5.10.5 Classroom Exercise 1

This site is in an area that receives about 58 inches of precipitation a year. Almost all of the precipitation is rain. This area has occasional freezing periods during the winter months, but these are infrequent and usually of short duration. During the Preliminary Rating, the maintenance person pointed out the water-seeps that occur almost year-round. He indicated that this condition is due mainly to precipitation in the area, but is also exacerbated by heavy irrigation during the summer months, of orchards on the slopes above the cut.

Determine the category score based on the benchmark criteria found on page 64.

Climate and Presence of Water on Slope Score =

5.11 Rockfall History Category

This category rates the historical rockfall activity at a site as an indicator of future rockfall events. Typically, the frequency and magnitude of past events is an excellent indicator of the type of events to expect. The benchmark criteria established for this category are:

ROCKFALL HISTORY	Few falls	Occasional falls	Many falls	Constant falls

5.11.1 Category Significance

The rockfall history directly represents the known rockfall activity at the site. This information is an important check on the potential for future rockfalls. If the score you give a section does not compare with the rockfall history, a review of the rating is advisable.

5.11.2 Criteria Narratives

3 points Few Falls Rockfalls occur only a few times a year (or less), or only during severe storms. This category is also used if no rockfall history data is available.

9 points Occasional Falls Rockfall occurs regularly. Rockfall can be expected several times per year and during most storms.

27 points Many Falls Typically, rockfall occurs frequently during a certain season, such as the winter or spring wet period, or the winter freeze/thaw, etc. This category is for sites where frequent rockfalls occur during a certain season but are not a significant problem during the rest of the year. This category may also be used where severe rockfall events have occurred.

81 points Constant Falls Rockfalls occur frequently throughout the year. This category is also for sites where severe rockfall events are common.

5.11.3 Sources of Information

This information is best obtained from the maintenance person responsible for the slope. There may be no history available at newly constructed sites or where documentation practices are poor. The maintenance cost at a site may be the only information that reflects the rockfall activity.

5.11.4 Classroom Exercise 1

During the Preliminary Rating, the maintenance person explained that rock falls frequently and that severe rockfall events occur on a regular basis, as shown below in figure 5.31.

Based on this information, use the criteria narratives on the previous page to determine the appropriate score for the Rockfall History Category.

Rockfall History Score = ________

5.12 Summary of Classroom Exercise 1

On the following page is a completed RHRS Field Data Sheet containing ODOT's actual detailed rating data.

RHRS FIELD DATA SHEET

HIGHWAY: Crown Point **REGION: 1**

HIGHWAY # 125	Beginning M.P. 4.06	[L] / R	Ending M.P. 4.48
COUNTY # 26	DATE 92 07 07	NEW	Rated By Chassie
CLASS [A] B	ADT 3,000	UPDATE X	Speed Limit 40

CATEGORY	REMARKS	CATEGORY SCORE
Slope Height 110 ft 70°/ 57°/ 30 ft. H.I. = 5 ft.		SLOPE HEIGHT 100
Ditch Effectiveness G M L [N]	Volume too large	DITCH EFFECT 81
Average Vehicle Risk 131 %		AVR 100
Sight Distance 330 ft Percent Decision Site Distance 55 %		SIGHT DISTANCE 36
Roadway Width 30 ft		ROADWAY WIDTH 20
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER
CASE 1		CASE 1
Structural Condition D C/F R A		STRUCT COND
Rock Friction R I U P C - S		ROCK FRICTION
CASE 2		CASE 2
Differential Erosion Features F O N [M]	Large dangerous overhang	DIF ER FEATURES 100
Difference in Erosion Rates S M L [E]		DIF ER RATES 81
Block Size/Volume 50 ft/[yd^3]	Up to 50,000 yd^3	BLOCK SIZE 100
Climate Precipitation L M [H] Freezing Period N [S] L Water on Slope N I [C]	Springs erode mudstone year round	CLIMATE 27
Rockfall History F O M [C]	Major events	ROCKFALL HISTORY 81
		TOTAL SCORE 726

COMMENTS: Rock on roadway occurs regularly. Large volume events occur on a 3 to 5-year cycle.

Before the rater leaves the site, several items should be checked to insure that all necessary information has been gathered.

1. Was the posted speed limit recorded?
2. Were photographs taken of the site?
3. Has enough information been gathered to develop a preliminary design and cost estimate?

Implementing an RHRS requires a significant expenditure of time and resources. Do not compound this expense by having to make return trips to get information that was overlooked.

5.13 Epilogue

This slope received a detailed rating in early 1990 as part of ODOT's RHRS implementation. Its high score ranked it as one of the highest priority slopes in the region, and it was targeted for a rockfall mitigation project in 1993 or 1994. However, in October 1991, a 370-foot long section of the overhang broke loose along a stress relief crack several feet back into the slope. Approximately 50,000 cubic yards of rock failed onto the roadway. Fortunately, traffic was stopped short of the site at the time of the failure. However, three construction workers installing guardrail were injured. This picture shows the cleanup effort to reopen the road.

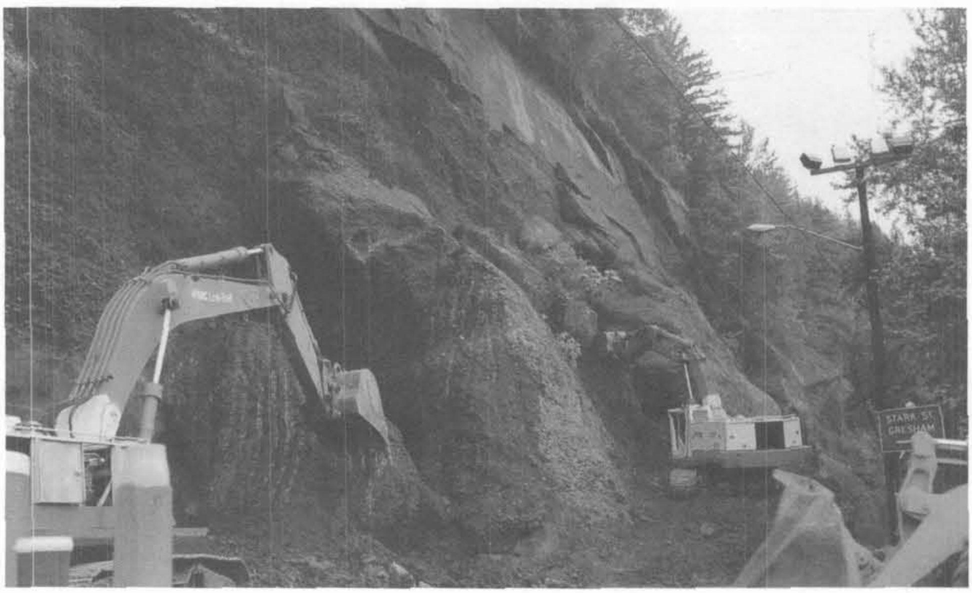


Figure 5.32 A major event.

CHAPTER 6: PRELIMINARY DESIGN AND COST ESTIMATE

It is important, when planning highway construction projects, to establish the desired result. The desired result is what determines such things as the project limits, the estimated construction costs, and the right-of-way needs. Trying to retrofit a different, more appropriate rockfall design after these factors have been established is frustrating, at best, and can be completely impossible.

The fourth step of the RHRS process accounts for this need by requiring that a preliminary design and cost estimate be included as part of the RHRS database. This information is used in the final phase of the prioritization process, when project limits are established and projects are advanced for construction.

6.1 Approach to Rockfall Control

During the detailed rating, the raters should gather enough site-specific information to be able to recommend which rockfall remediation measures are appropriate for the site. More than one design approach will likely be needed for each site.

For management to make informed decisions on whether to take a total correction approach or only reduce the rockfall hazard, they will need to understand the costs and benefits associated with both choices. Hazard reduction measures can vary from limited duration improvements such as slope scaling, to more aggressive steps, such as installing slope screening.

Frequently, a combination of several techniques will work best. At this early stage, the goal is to provide an appropriate method to deal with the rockfall problem. These preliminary concepts can later be refined by more detailed investigation and analysis.

6.2 Rockfall Remediation Designs

Covering the field of rock mechanics is beyond the scope of this manual. An excellent reference on the subject is the Federal Highway Administration's publication No. FHWA-TS-89-045, titled "Rock Slopes: Design, Excavation, Stabilization," prepared by Golder and Associates, Seattle, Washington.

The value of having personnel skilled in this area can not be stressed too much. Experience is the best predictor of the effectiveness of a rockfall remedial design. There are too many gaps in our understanding of the mechanical properties of rock masses to rely wholly on an analytical approach.

6.2.1 Common Rockfall Remediation Techniques

Several techniques are routinely used to deal with rockfall. The choice of techniques is dependent on several factors, including the size or volume of anticipated rockfall, access to the rockfall source, maintenance limitations, the construction budget, and the desired result. The following table describes common rockfall mitigation techniques and their uses.

Table 6.1 Rockfall Mitigation Techniques

Technique	Description/Purpose
Scaling	Removal of loose rock from slope by means of hand tools and mechanical equipment. Commonly used in conjunction with most other design elements.
Slope Screening	Placement of wire or cable mesh on a slope face. Controls the descent of falling rock. Rockfall accumulates near the base of the slope for removal.
Catch Fences	Wire or cable mesh draped from a fence to the roadside ditch. The fence (impact section) captures the falling rock and channels it beneath the mesh. The mesh attenuates the rockfall energy, allowing the rock to come to rest short of the roadway, in the catchment area.
Excavation	Removal of slope material in order to create a rock fallout area adjacent to the roadway. Use of modern construction practices improves the condition of redeveloped cut slopes.
Artificial Reinforcement	Improvement of slope stability by the installation of mechanical supports including rock bolts, rock dowels, and cable lashing. Used to hold material in place on the slope.

Shotcrete	Mortar or concrete pneumatically projected at high velocity onto a slope. Primarily used to halt the effects of erosion by protecting the shot surface from the elements. Also helps retain rock on the slope.
Barrier Systems	Installation of either rigid or flexible barriers systems capable of handling the energy developed in a falling rock. Examples include Jersey barriers, gabion baskets and woven cable fences. Systems are normally placed adjacent to the roadway for ease of maintenance.
Drainage	Reduction of the water level within a slope through installation of horizontal drains or adits. Commonly used in conjunction with other design elements.

6.2.2 Reviewing Preliminary Designs

Inexperience can result in the wrong application of the above techniques. A review of the design concept by an experienced staff member is recommended before the cost estimate is calculated, or used to make decisions on project development.

6.3 Cost Estimate

The cost estimate is an important element of the rockfall database. This information will be considered when final project priorities are established. The costs of these different design elements can vary a great deal nationally. For that reason, no costs are included in this document.

The rockfall design cost calculated is strictly the cost of the rockfall remedial measures. A project may eventually include pavement widening, guardrail installation, structural pavement overlay, etc. These cost items, as well as typical mobilization, engineering, and contingency costs are not included as part of the RHRS cost estimate. This approach simplifies the estimation process, since, when rockfall sites and the costs of dealing with them are compared, these additional cost items will not interfere.

A sample worksheet is shown on the next page.

ROCKFALL MITIGATION COST ESTIMATE WORKSHEET

State Hwy Name: ______________________________ #__________
Beginning M. P. ______________________
L or R of Centerline ______________________
Ending M. P. ______________________
County Name ______________________ #__________
Date of Rating(YYMMDD) ______________________
Name of Designer ______________________
Average Daily Traffic ______________________
Posted Speed Limit ______________________
RHRS Score ______________________

DESIGN OPTION DESCRIPTION

____
____
____
____

This approach is a rockfall ____ correction ____ hazard reduction design.

DESIGN ELEMENTS

1.	______________________	5.	______________________
2.	______________________	6.	______________________
3.	______________________	7.	______________________
4.	______________________	8.	______________________

COST ESTIMATE

Quantity X Unit Cost

1. ____________X__________ = $ ____________________
2. ____________X__________ = $ ____________________
3. ____________X__________ = $ ____________________
4. ____________X__________ = $ ____________________
5. ____________X__________ = $ ____________________
6. ____________X__________ = $ ____________________
7. ____________X__________ = $ ____________________
8. ____________X__________ = $ ____________________

TOTAL OPTION COST: $ ____________________

Cost/RHRS Score Ratio ____________________

This work sheet is helpful in developing a cost estimate. The information on the sheet documents the location of the rockfall, a narrative of the design concept, a list of the design elements, a list of the costs of the design elements, the total option cost, and the cost-to-RHRS score ratio. An agency may need to modify this sheet to meet its specific needs.

6.4 Classroom Exercise 1

A preliminary design and cost estimate for site 1 is included below. Note that the cost estimate includes only the cost of the rockfall remediation design elements.

DESIGN OPTION DESCRIPTION

Trim blast slope to create a 22-foot wide fallout area. Shotcrete lower 15 feet of cut to halt differential erosion. Install Jersey barrier at edge of pavement.

This approach is a rockfall _X_ correction ___ hazard reduction design.

DESIGN ELEMENTS

1.	Excavation	5.	
2.	Trim blasting	6.	
3.	Shotcrete	7.	
4.	Jersey Barrier	8.	

COST ESTIMATE

	Quantity	X	Unit Cost	=	$
1.	121,000 cu yds	X	3.50	=	$ 423,500
2.	70,000 ln ft	X	2.00	=	$ 140,000
3.	27,000 sq ft	X	3.00	=	$ 81,000
4.	1,584 ln ft	X	22.00	=	$ 34,900
5.		X		=	$
6.		X		=	$
7.		X		=	$
8.		X		=	$

TOTAL OPTION COST: $ 679,400.00

Cost/RHRS Score Ratio 936

CHAPTER 7: PROJECT IDENTIFICATION AND DEVELOPMENT

The essential benefit of implementing the RHRS is a reduction in the system-wide rockfall potential. This benefit can only be realized once rockfall remedial projects are developed from the resulting database.

7.1 Project Identification

There are several ways of using the information gathered during the previous stages of the RHRS process. Following are four suggested methods to identify rockfall remediation projects for construction.

7.1.1 Score Method

Projects can be advanced on the basis of their scores. This is the most obvious use of the system. Realizing that the most hazardous slopes are those at the top of the list makes it reasonable to fund those slopes for construction as funds become available.

The main drawback to using this method is that too often the highest rated slopes are among the most costly to repair. A decision must be made by the agency whether to proceed from the top of the list down or to attempt to improve as many high priority sites as possible with the funds available.

7.2.2 Ratio Method

Projects can be advanced based on their scores relative to their estimated construction costs. This is, in effect, a variation of the benefit/cost method. The preliminary cost estimate for the top-rated slopes is divided by the RHRS score and a list is generated with the lowest-dollar-to-RHRS-point ratios at the top. Projects developed from this list will provide the greatest systemwide hazard reduction with a fixed amount investment. The 100 highest rated slopes are a reasonable starting point for implementing this approach.

If this approach is used, some of the highest rated slopes may be left unattended because of their higher cost. If this situation is a concern, development of projects from both lists may be a solution. With either method, significant progress is made toward reducing the risk associated with rockfall.

7.2.3 Remedial Approach Method

Projects can be developed on the basis of two or more sections having similar remedial designs. Rockfall sections containing similar construction features, as identified during the preliminary design and cost estimate process, can be grouped into a single project. Finding enough qualified contractors versed in constructing a broad array of rockfall remediations is difficult. Limiting the complexity of the contract should alleviated this problem.

An example of this approach would be to take a length of highway and combine into one project all of the sections that are earmarked for slope screening. A larger quantity of slope screening will be contracted. This method can result in more straightforward, easily managed contracts, with lower unit bid prices.

7.2.4 Proximity Method

Projects can be developed on the basis of proximity of rockfall sites along a section of roadway. Because the rockfall sites have been identified and remedial measures properly determined, a larger contract can be let. This method may result in lower unit bid prices and an overall savings for mobilization.

An example of this method would be to group all "A" rated slopes along a 20-mile stretch of roadway into one project. When using this approach, it may be useful to consider including the "B" rated slopes within the 20-mile section. This method will remove an entire section of roadway from the RHRS database and clearly demonstrate that progress is being made.

All of the above approaches rely on the data from the RHRS database generated from implementation and periodic updates.

7.2 Rockfall Related Accidents

It should be noted that even though one "A" slope receives a score of 700, while another receives a score of 600, both have the potential of sending rock onto the roadway. Agencies will always be expected to react to rockfall accidents, no matter where the affected section appears on the RHRS priority list. An agency should resist the tendency to overreact. Sites where an accident has occurred should be reevaluated with the detailed rating to determine if the rockfall incident has increased or decreased rockfall potential. The level of investment at the site should be consistent with the new potential relative to the other identified sites.

CHAPTER 8: ANNUAL REVIEW AND UPDATE

The final step in the RHRS process is to perform a review of all rated slopes. This review should be conducted annually. The review (and update) is an important step because it protects an agency's original investment in creating the RHRS database. The value of the information as both a project development tool and a reliable source of data in court is assured.

8.1 Review and Update

If any slopes in the database have been modified by construction or maintenance activities, they should be reviewed and either removed from the RHRS system or re-rated. Any newly constructed slopes should also be evaluated and if necessary added to the database. Eventually, all slopes in the database including the "B" rated slopes should be evaluated with the detailed rating and have preliminary designs drawn up and cost estimates calculated.

Existing preliminary designs for any rockfall section whose rating has changed due to site modifications should be reviewed. Changes in site conditions can make the old designs inappropriate. Cost estimates should be updated periodically as the unit bid prices change.

Once all slopes have been rated, an agency may redefine what constitutes an "A" or "B" slope using a range of scores established by the agency rather than the subjective evaluation criteria applied during the preliminary rating. The agency may elect to drop the letter designation entirely.

8.2 Review Purpose

Conditions in nature can change unexpectedly. The effects of a severe winter, or heavier than normal precipitation in the spring or fall, can hasten changes that affect the potential for future rockfall events. Man's actions can also cause changes in slope conditions. At times, the potential for rockfall can decrease.

Figures 8.1 and 8.2 show a rockfall event that reduced the potential for further rockfall by removing the unstable block.

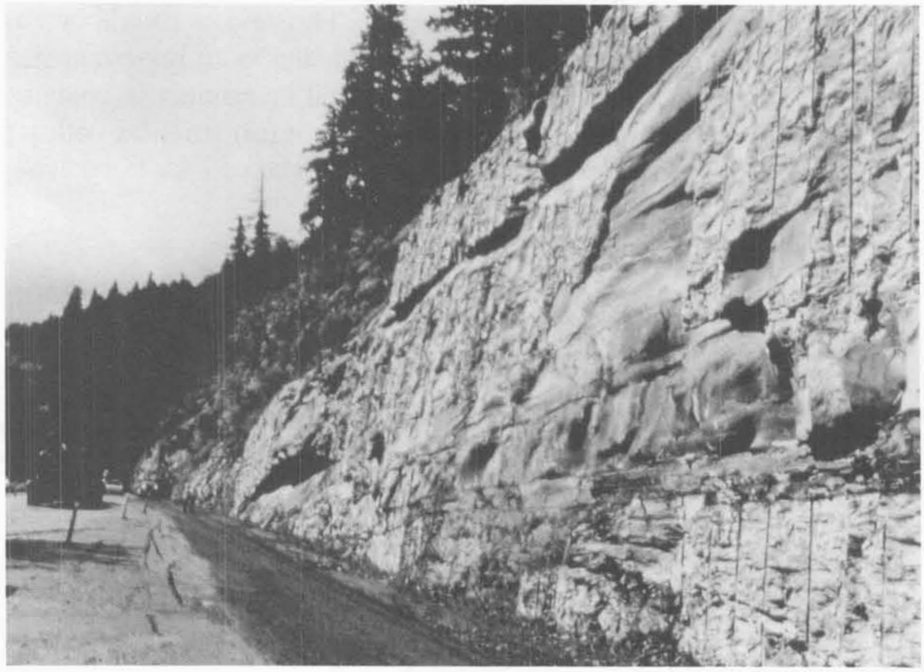


Figure 8.1 Note the large overhang in the distance.

Figure 8.2: When the large block fell, some of the debris reached the roadway. Future rockfalls, which will be smaller, should be retained in the ditch.

Not all changes that can affect a slope's rating are as obvious as those illustrated in this example. At times, the changes can be difficult to discern. The rater should refer to photographs taken during previous inspections to help identify changes. It also is beneficial to review recent maintenance information to determine if there has been any significant work at the site that could affect the slope's rating.

The review and update process should be ongoing. For the sake of economy, much of the work can be accomplished throughout the year while the raters are commuting to and from job-sites to carry out other responsibilities.

CHAPTER 9: THE ROCKFALL DATABASE MANAGEMENT PROGRAM

The RHRS creates a large amount of information about the location and condition of the rockfall sites within an agency's jurisdiction. For an agency to benefit from this information, it must be able to use the data effectively in the decision making process. A computer database is required for this.

The FHWA has created a PC database program entitled the Rockfall Database Management Program (RDMP). The RDMP is designed specifically to meet the needs of the RHRS user.

9.1 The Value of an Automated Database (RDMP)

A computer database is an essential part of the RHRS. There are many ways of using the RHRS data. An automated database such as RDMP provides the flexibility to present the data in several different formats.

The RDMP is a stand alone system that requires no supporting software. A copy of the program and the user's manual is provided at no charge to the states. The operations of the program are user friendly, with built in safety checks. The RDMP is an excellent and highly recommended tool.

9.2 Tailoring the Database

The RDMP was designed to match the system used by the Oregon Department of Transportation. Therefore ODOT's method of identifying rockfall sites by region, highway, and mile point is followed. This method may not be consistent with how site locations are documented elsewhere. If assistance is needed to tailor the RDMP to another agency's needs, that help is available through the program's author:

Barry D. Siel, P.E.
FHWA Regional Geotechnical Engineer
555 Zang Street #400
Lakewood, Colorado 80228
(303)969-6718

9.3 About the Program

The user's manual that accompanies the software contains step-by-step instructions for installing and operating the Rockfall Database Management Program. The RDMP is actually two programs. The first is entitled RFHQ and is intended for use by the agency's headquarters office. The second, RFRG, is for use by the agency's regional offices. RHRS rockfall data is collected by the regional offices and entered into RFRG. Periodically, updated copies of the regional database are transferred from the regional offices to the headquarters office via computer floppy disks or a modem. The headquarters office can than combine all regional data for use in developing statewide strategies.

The headquarters and regional versions of the RDMP have virtually the same features, functions, and capabilities. They differ only in that the regional program is a single database for a region, while the headquarters program can work with each region's database separately, or with all the regional databases combined into a statewide database.

9.3.1 Generating Reports

Reports can be generated from the information contained in the database through sort and query processes. In addition the report information can be ranked. The sort menu screen is shown below as an example.

```
                    ROCKFALL HAZARD RATING SYSTEM

          Main State Menu

  A. Sort records
  B. Query records
  C. Rank present sort/query records
  D. View present sort/query records
  E. Start new sort/query/ranking
  F. Print present sort/query records
  G. Print a single record
  H. Save present sort/query records

  X. Exit
```

Figure 9.1 Screen print of the main state menu.

```
ROCKFALL HAZARD RATING SYSTEM

Sort Hierarchy                 Sort Selection List

1. REG                  Total Score = TSC          Width Score = WTH
                               Cost = CST        Roadway Width = KW5
2. HWY               Cost/T. Score = CTS          Case 1 Score = SC1
                        Slope Score = SLP       Friction Score = RCK
3. BMP                 Slope Height = KW1         Case 2 Score = SC2
                        Ditch Score = DCH        Erosion Score = ERS
4.                       Risk Score = RSK          Block Score = BLK
                     Distance Score = DST        Climate Score = CLM
5.                  Actual Distance = K11        History Score = HST
                             County = CTY              Beg. MP = BMP
CTRL-W to sort              Highway = HWY         Avg. Traffic = ADT
 ESC to exit                 Region = REG         Posted Speed = MPH
```

Figure 9.2 Sort menu with a request to sort database by region, highway and beginning mile point.

```
ROCKFALL HAZARD RATING SYSTEM

    Ranking                    Rank Selection List

Rank by:                Total Score = TSC          Width Score = WTH
                               Cost = CST        Roadway Width = KW5
 ESC to exit         Cost/T. Score = CTS          Case 1 Score = SC1
                        Slope Score = SLP       Friction Score = RCK
                       Slope Height = KW1         Case 2 Score = SC2
                        Ditch Score = DCH        Erosion Score = ERS
                         Risk Score = RSK          Block Score = BLK
                     Distance Score = DST        Climate Score = CLM
                    Actual Distance = K11        History Score = HST
```

Figure 9.3 Ranking menu. The largest value in the category selected for ranking will be ranked 1.

9.3.2 Example Reports

Excerpts from RDMP reports are included below to demonstrate the flexibility and usefulness of the program.

ROCKFALL HAZARD RATING SYSTEM

REG	HWY	BEGINNING MILE PT	CNTR LINE	DATE OF RATING	PRELIM COST ESTIMATE	COST/ SCORE	CLASS	TOTAL SCORE	RANK
5	010	30.14	L	04/10/90	$ 7,000,000	11,647	A	601	1
3	018	23.44	R	07/26/91	$ 930,761	1,708	A	545	2
2	162	43.32	L	06/12/91	$ 570,000	851	A	670	3
2	162	44.52	L	06/07/90	$ 350,000	640	A	547	4
5	413	1.00	L	05/10/90	$ 408,000	638	A	639	5
2	016	84.93	L	04/01/92	$ 400,000	552	A	725	6
5	005	220.50	L	09/12/91	$ 200,000	394	A	508	7
2	162	40.47	L	12/19/91	$ 210,000	381	A	551	8
2	162	39.65	L	11/25/91	$ 180,000	354	A	509	9
2	162	40.00	L	11/26/91	$ 140,000	262	A	534	10
2	162	41.03	L	11/26/91	$ 100,000	181	A	552	11
2	162	40.80	L	11/26/91	$ 110,000	165	A	668	12
2	162	41.70	L	12/23/91	$ 90,000	161	A	558	13
2	039	1.67	R	12/03/91	$ 55,000	103	A	535	14
2	016	59.72	L	11/25/91	$ 40,000	79	A	508	15

Press ENTER to continue or ESC to exit

Figure 9.4 Data ranked by cost-to-RHRS score.

ROCKFALL HAZARD RATING SYSTEM

REG	HWY	BEGINNING MILE PT	CNTR LINE	DATE OF RATING	PRELIM COST ESTIMATE	COST/ SCORE	CLASS	TOTAL SCORE	RANK
2	016	84.93	L	04/01/92	$ 400,000	552	A	725	1
2	162	43.32	L	06/12/91	$ 570,000	851	A	670	2
2	162	40.80	L	11/26/91	$ 110,000	165	A	668	3
5	413	1.00	L	05/10/90	$ 408,000	638	A	639	4
3	018	55.97	L	07/26/91	$ 30,000	49	A	612	5
5	010	30.14	L	04/10/90	$ 7,000,000	11,647	A	601	6
2	162	41.19	L	11/24/91	$ 45,000	77	A	583	7
2	162	41.70	L	12/23/91	$ 90,000	161	A	558	8
2	162	41.03	L	11/26/91	$ 100,000	181	A	552	9
2	162	40.47	L	12/19/91	$ 210,000	381	A	551	10
2	162	44.52	L	06/07/90	$ 350,000	640	A	547	11
3	018	23.44	R	07/26/91	$ 930,761	1,708	A	545	12
2	039	1.67	R	12/03/91	$ 55,000	103	A	535	13
2	162	40.00	L	11/26/91	$ 140,000	262	A	534	14
2	162	39.65	L	11/25/91	$ 180,000	354	A	509	15

Press ENTER to continue or ESC to exit

Figure 9.5 Cost-to-RHRS data ranked by total score.

CHAPTER 10: CLASSROOM EXERCISES

A great deal of information has been exchanged up to this point. Two additional classroom exercises (numbers 2 and 3) are included to provide the participant with more experience in applying the RHRS.

10.1 Purpose

The purpose of the classroom exercises is to give the participants the opportunity to resolve any questions they may have. The goal is to standardize the application of the RHRS as much as possible prior to the field exercises. The classroom forum will allow students to hear how others interpret site characteristics and score the categories. These exercises will also demonstrate the need to practice together to reduce the range of scores a particular rockfall site can receive from different raters.

10.2 Exercise Procedure

For both classroom exercises, a preliminary and detailed rating will be performed. The preliminary design concepts and associated costs will be prepared and discussed if time allows. Required information will be provided by the instructor or interpreted from photographs included in the manual. Scoring graphs and tables along with worksheets will be provided.

10.2.1 Exercise 2 Procedure

Questions will be answered and guidance will be provided by the instructor during problem 2. Discussion between participants is encouraged. A review of the results with a question and answer period will conclude the exercise.

10.2.2 Exercise 3 Procedure

The participants will work more independently during problem 3. This exercise will allow each person to determine how their use of the RHRS process compares with the others in the class. Any major differences in this regard should be resolved during the concluding discussion period.

10.3 Exercise 2

As you enter the heart of Oregon City on Highway 99E, the maintenance foreman accompanying you points out that this highway section is a significant problem in his district. At least four rockfall related accidents and two major rockfall events have occurred in the last 5 years. Also, his crews working in the area have told him about numerous small rockfall accidents that were not reported. The size of the rockfall ranges from 3 inches up to 3 feet. Because of this, the site is patrolled by maintenance forces twice a day throughout the year and a third, night shift, patrol is added during the winter months. During periods of bad weather maintenance patrols check the site several times a shift. The site is shown in figures 10.1 through 10.5 on the following pages.

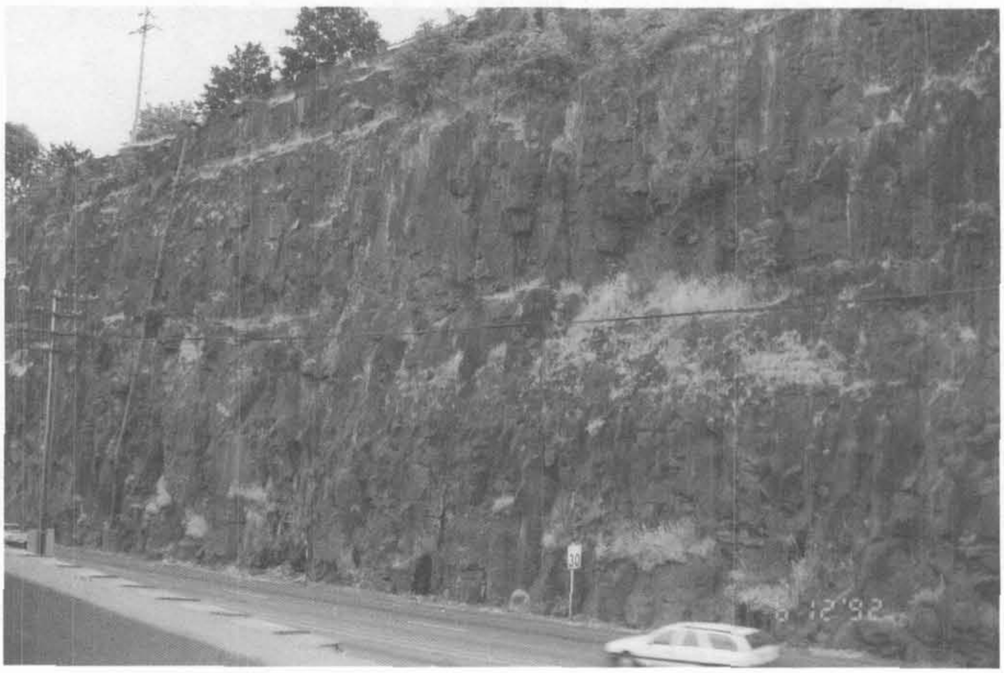


Figure 10.1 Overview of site 2. Slope height?

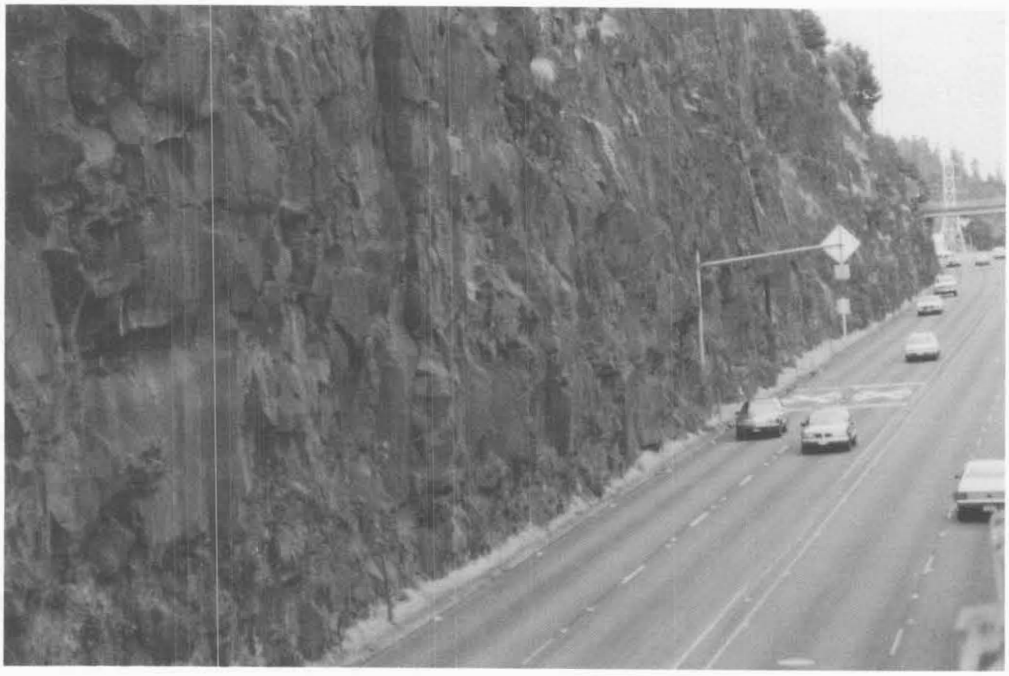


Figure 10.2 Ditch effectiveness?

Figure 10.3 AVR? Note the posted speed limit.

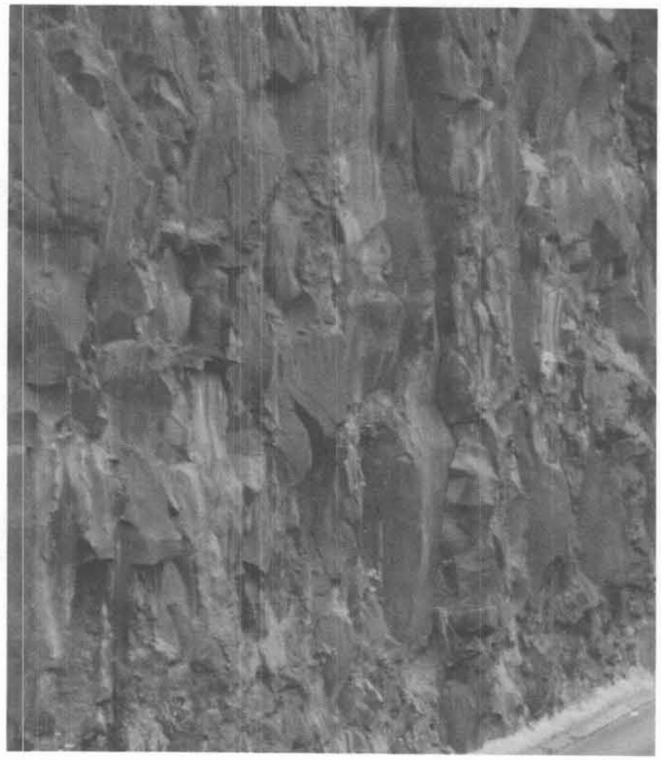


Figure 10.4 Geologic character?

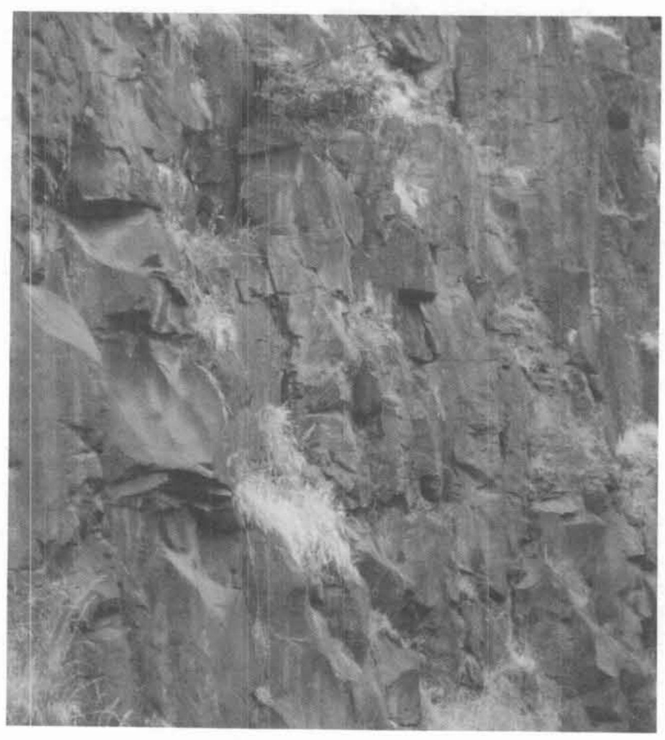


Figure 10.5 Block size?

10.3.1 Preliminary Rating

The rockfall section extends from Mile Point 12.62 to 12.94. The posted speed limit is 30 miles per hour and the ADT is 18,300 cars/day. The rock is highly fractured, and blocks are likely to come down in the future. There is no ditch or catchment area available. Therefore, any rock that falls will likely reach the roadway.

Using the photographs, the data above, and the historic information given by the maintenance person, complete the upper portion of the Rockfall Rating Data Sheet provided by the instructor. Include appropriate information in the Comments section. Classify the slope by using the preliminary rating criteria discussed in chapter 3.

10.3.2 Detailed Rating

The following data were gathered at the site and will be used in completing the Detailed Rating. Participants should use the photographs to determine where the site conditions fall within the category criteria. Score the categories by referring to the information covered in chapters 4 and 5.

Slope Height	A city street is present near the top of the slope. The access makes it possible to drop a tape over the edge and measure the near vertical slope height directly. It is 116 feet high.
Ditch Effectiveness	There is no ditch or catchment area available. Uncontrolled blasting techniques used to construct this slope, combined with a highly fractured structural geology pattern, have produced a an irregular slope face. Many launch features are present throughout the slope. Some of these were caused by natural contacts between basalt flows, others are ledges left between lifts during blasting, and still others are ledges created by large rocks that have already fallen from the slope.

Average Vehicle Risk	The site extends from Mile Point 12.62 to 12.94. The posted speed limit is 30 miles per hour, and the ADT is 18,300 cars/day.
Decision Sight Dist.	Although cars entering the site from the north are coming out of a tunnel, sight distance is generally good. The measured sight distance is 450 feet.
Roadway Width	The high ADT creates problems in measuring the width of the lanes. Relying on the rater's experience with standard highway design, the roadway width was estimated to be 46 feet.
Geologic Character	The general structural pattern is a combination of blocky and columnar basalt flows. On this steep slope the blocky pattern, combined with the 10-to-20-foot long vertical joints, causes some rocks to topple from the slope. With this structural pattern, slope stability is heavily influenced by elevated ground- water levels caused by storms and by ice jacking. (In support of this view, the maintenance foreman had stated, during the preliminary rating, that the crew had to pay particular attention to this slope during storms and in the winter.) In general, the frictional resistance between joint surfaces is good. The surfaces are mostly micro rough to micro smooth and macro irregular to undulating.
Block Size or Volume per Event	Because of the blocky fracture pattern, most of the rockfall events consist of either individual blocks or just a few blocks at a time. The maintenance foreman mentioned two events of about 5 to 10 cubic yards but these kinds of events are rare. An inspection of the slope reveals many blocks in the 2-to-3-foot range that could fail. This finding coincides well with the information provided by the maintenance foreman

	that occasionally, blocks up to approximately 3 feet in one dimension fall here.
Climate and Water on Slope	This site gets approximately 55 inches of precipitation a year, mostly as rain. There are frequent freezing cycles in the winter, but they are of short duration. For most of the year, water seeps from the joints and fractures throughout much of the slope.
Rockfall History	Refer to the information provided by the maintenance foreman.

10.3.3 Preliminary Design and Cost Estimate

Site conditions that would affect the remediation design should be noted and considered while in the field. Many remediation plans can be eliminated from further consideration in this way.

An example of additional information that should be collected for design purposes is the presence of the masonry wall at the top of the cut. This wall is of historical significance and needs to be avoided during remediation. The following considerations are also significant:

> This limitation precludes construction of a rock fallout area through excavation as a remediation technique.
>
> The geologic structure does not lend itself to remediation solely through artificial reinforcement.
>
> There is not enough room adjacent to the highway to install a barrier.
>
> The slope is too steep to install a catch fence.

Participants should use the provided Cost Estimate Worksheet to document the preliminary design and cost estimate. The cost of the remediation should be considered along with the constructibility of the design. A completed worksheet is provided on the next page.

Page ____ of ____
Design Option ____

ROCKFALL MITIGATION COST ESTIMATE WORKSHEET

State Hwy Name:	99E	# 001E
Beginning M. P.	12.62	
L or R of Centerline	Left	
Ending M. P.	12.94	
County Name	Clackamas	# 3
Date of Rating (YYMMDD)	91 08 08	
Name of Designer	Pfeiffer	
Average Daily Traffic	18,300	
Posted Speed Limit	30	
RHRS Score	547	

DESIGN OPTION DESCRIPTION

Install slope screening anchored to slope with 3-foot anchors on 10-foot centers. Install approximately 25 10-foot rock bolts in identified key blocks.

This approach is a rockfall ____ correction X hazard reduction design.

DESIGN ELEMENTS

1.	Slope screening	5.	
2.	Screen anchors	6.	
3.	Rock bolts	7.	
4.		8.	

COST ESTIMATE

	Quantity	X	Unit Cost	=	$
1.	81,600 ft^2	X	2.00	=	$ 163,200
2.	900 ea	X	50.00	=	$ 45,000
3.	250 ln ft	X	25.00	=	$ 6,250
4.		X		=	$
5.		X		=	$
6.		X		=	$
7.		X		=	$
8.		X		=	$

TOTAL OPTION COST: $ 214,450.00

Cost/RHRS Score Ratio 392

10.4 Exercise 3

The Clackamas River Gorge Highway east of Estacada, Oregon, includes a 15-mile stretch, from M.P. 30 to M.P. 45, of nearly continuous rockfall problems. A rater doing a Slope Survey/Preliminary Rating of this section would need to rely heavily on the information provided by the maintenance person to define the rockfall sections. The site is shown in figures 10.6 through 10.10 on the following pages.

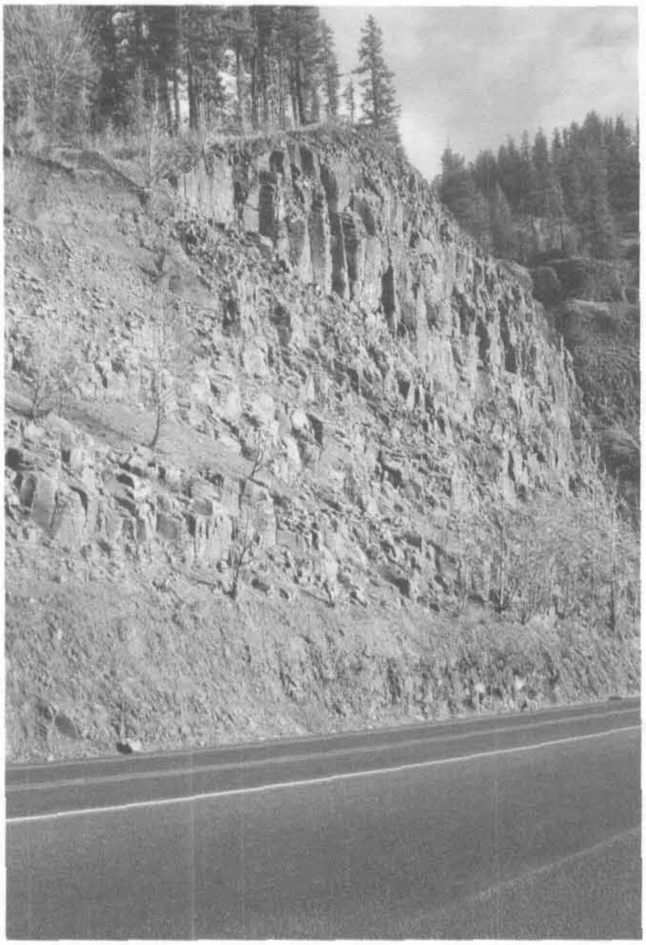


Figure 10.6 Overview of site 3. Slope height?

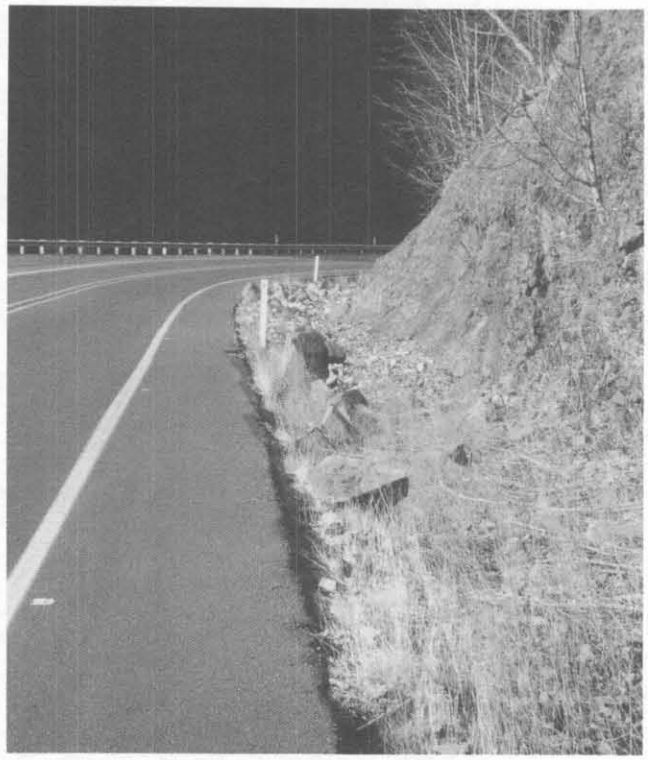


Figure 10.7 10-foot ditch is inadequate. Seventy-five percent of rockfall reaches the roadway. Ditch effectiveness?

Figure 10.8 Decision sight distance? Roadway width?

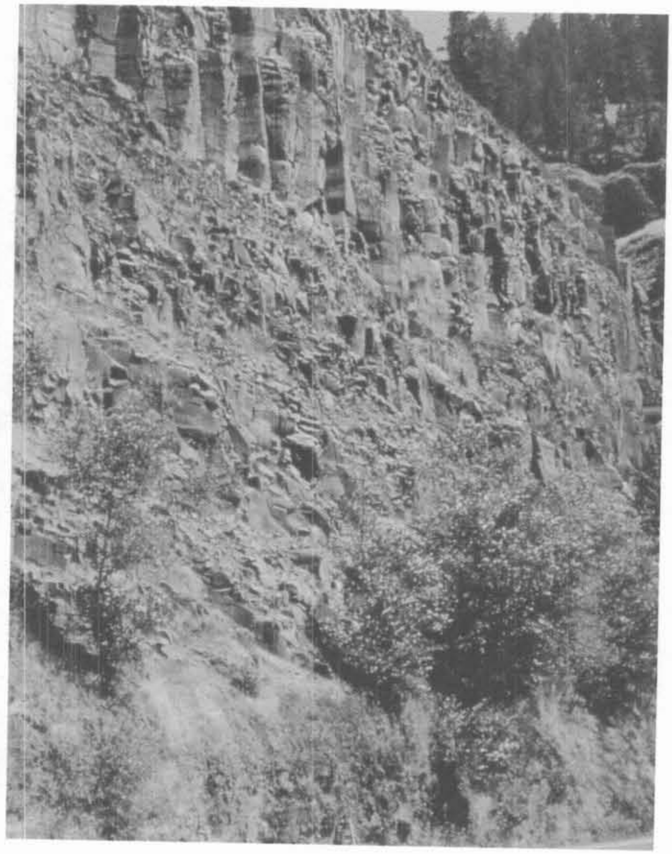


Figure 10.9 Geologic character?

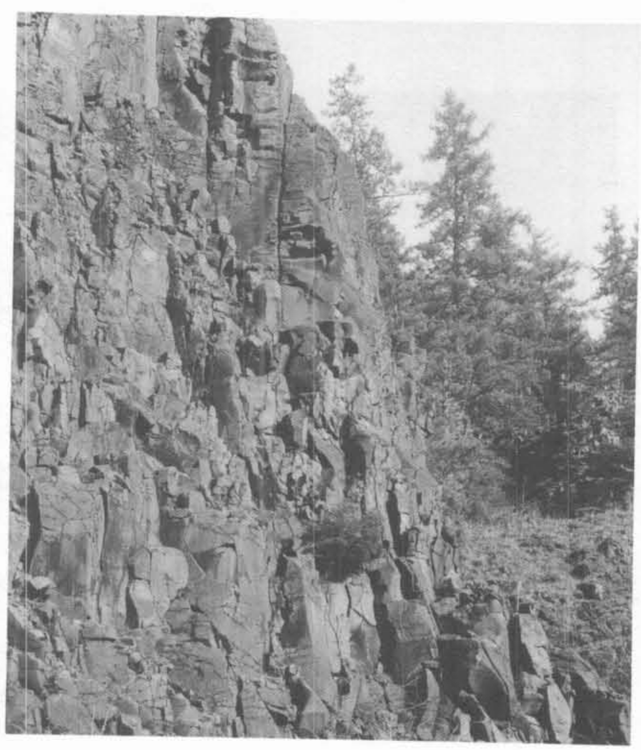


Figure 10.10 Block size?

10.4.1 Preliminary Rating

This particular rockfall section extends from M.P. 37.25 to M.P. 37.60. Based on the maintenance worker's statements, it is considered to be one of the worst sites in their district. Most of the rockfall problems occur during the winter months. Maintenance crews perform two rock patrols a day between October and April. They also have a policy of checking this area after every significant rain storm year round. Historically, the height of the cut, the launching features, and the small fallout area have combined to put rocks on the roadway on a regular basis.

Using the photographs together with the above data and the historic information provided by the maintenance person, complete the upper portion of the Rockfall Rating Data Sheet provided by the instructor. Include appropriate information in the Comments section. Classify the slope by using the preliminary rating criteria discussed in chapter 3.

10.4.2 Detailed Rating

The following data from the site will be used to complete the Detailed Rating. Participants should use the photographs to determine where the site conditions fall within the category criteria. Score the categories by referring to the information covered in chapters 4 and 5.

Slope Height	The slope is too irregular to measure the height of the slope directly. The rater will use the method outlined in section 5.3.2. The instrument height of the clinometer is 5 feet. The X distance from edge of pavement to edge of pavement is 44 feet. The α angle is 65 degrees; the ß angle is 60 degrees.
Ditch Effectiveness	The width of the ditch is 10 feet, inadequate for a slope this high. The numerous slope irregularities and benches compound this problem. About 75% of the rockfall reaches the

	roadway. Only rockfall from the lower portion of the slope is contained in the catchment area.
Average Vehicle Risk	The rockfall section extends from Mile Point 37.25 to 37.60. The posted speed limit is 45 miles per hour. Average Daily Traffic is 2,800 cars per day.
Decision Sight Dist.	Drivers approaching the rockfall section from the west pass through a very sharp curve. A site distance of 240 feet was measured with the roller tape.
Roadway Width	Just beyond the sharp curve at the west end of the section, the pavement widens to 44 feet from edge of pavement to edge of pavement. There are only two travel lanes. Additional pavement width is provided for a turnout and parking area for the Big Eddy Rest Area, which is just beyond the rockfall section to the east.
Geologic Character	The geology of the site consists of a series of relatively horizontal basalt flows. The rock ranges from very highly fractured to columnar basalt with widely spaced fractures. In the columnar units, some of the cooling joints are 15 to 20 feet in length. As the slope weathers, these columns become prone to toppling failures. The joint surfaces of the columns are micro smooth and range from undulating to planar.
Block Size Volume per Event	Columns of basalt that appear to be about 5 to 8 feet in one dimension can be seen in the upper portion of the slope. However, the maintenance crews report that these blocks break up as they fall. Rock on the road seldom exceeds three feet in any dimension. As falling rocks descend, they dislodge many other rocks, creating a rockfall event on the road that typically contains

approximately five cubic yards of material.

Climate and Water on Slope — The Clackamas River Gorge cuts through the western foothills of the Cascade Mountains, which receive abundant precipitation. Precipitation at the site is mostly rainfall and averages about 90 inches per year. The elevation of the site is high enough that freezing and thawing cycles are common in the winter.

Rockfall History — Refer to the information provided by the maintenance foreman.

10.4.3 Preliminary Design and Cost Estimate

As always, Site conditions that would affect the remediation design should be noted and considered while in the field.

It is important to emphasize the need to gather and note design information during the detailed rating. Additional site trips to gather data cost money and should be avoided.

Several aspects of this site should be noted.

> The site is located in the Clackamas River Gorge, which is designated as a scenic area by the U. S. Forest Service. Visual impacts should be minimized.
>
> Improvement of sight distance should be considered.
>
> The site's history of producing events up to five cubic yards precludes use of slope screening or low energy catch fences.

The participants should use the Cost Estimate Worksheet to document the preliminary design and cost estimate. The cost of the remediation should be considered along with the constructibility of the design. A completed worksheet is provided on the next page.

ROCKFALL MITIGATION COST ESTIMATE WORKSHEET

State Hwy Name:	Clackamas	#	171
Beginning M. P.	37.25		
L or R of Centerline	Left		
Ending M. P.	37.60		
County Name	Clackamas	#	3
Date of Rating (YYMMDD)	91 10 17		
Name of Designer	Pierson		
Average Daily Traffic	2,800		
Posted Speed Limit	45		
RHRS Score	575		

DESIGN OPTION DESCRIPTION

Excavate the intermediate slope bench to create an improved (22-foot wide) rock fallout area at highway grade. Install standard Jersey Barrier at edge of pavement.

This approach is a rockfall ____ correction _X_ hazard reduction design.

DESIGN ELEMENTS

1. Excavate (Bench)
2. Controlled blasting
3. Standard Jersey Barrier
4. ________
5. ________
6. ________
7. ________
8. ________

COST ESTIMATE

	Quantity	X	Unit Cost	=	$
1.	13,200 cu yd	X	4.00	=	$ 52,800
2.	12,580 ln ft	X	2.00	=	$ 25,160
3.	1,850 ln ft	X	22.00	=	$ 40,656
4.		X		=	$
5.		X		=	$
6.		X		=	$
7.		X		=	$
8.		X		=	$

TOTAL OPTION COST: $ 118,616.00

Cost/RHRS Score Ratio 206

10.5 Summaries of Classroom Exercises

The following table summarizes the results of the three classroom exercises. Included are the Detailed Rating Category Scores, the total Detailed Ratio Score, the preliminary design cost estimate, and the cost estimate to total RHRS Score ratio.

Table 10.1 Summary of Classroom Exercises

CATEGORY	EXERCISE 1	EXERCISE 2	EXERCISE 3
Height	100 (110 feet)	100 (116 feet)	100 (401 feet)
Ditch	81	100	27
AVR	100 (131%)	100 (813%)	55 (91%)
DSD	36 (330 feet) (55%)	3 (450 FEET) (100%)	100 (240 FEET) (36%)
Width	20 (30 feet)	2 (48 feet)	3 (44 feet)
Geol Char	100 81	81 9	81 20
Block/Volume per event	27 (3 feet) 100 (50 yd^3) 27	27 (3 feet) 19 (8 yd^3) 50	27 (3 feet) 6 (5 yd^3) 81
Climate	81	75	81
History			
TOTAL SCORE	726	547	575
COST ESTIMATE	$679,400.00	$214,450.00	$118,616.99
COST ESTIMATE/ RHRS RATIO	936	392	206

On the next two pages are the completed RHRS Field Data Sheets for classroom Exercises 2 and 3, respectively.

RHRS FIELD DATA SHEET

HIGHWAY: 99E REGION: 1

HIGHWAY # 1E	Beginning M.P. 12.62	[L] / R	Ending M.P. 12.94
COUNTY # 3	DATE 91 08 07	NEW	Rated By Siel
CLASS [A] B	ADT 18,300	UPDATE	Speed Limit 30

CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 116 ft °/ °/	Access to top of slope. Height measured with tape.	SLOPE HEIGHT	100
Ditch Effectiveness G M L [N]	None	DITCH EFFECT	100
Average Vehicle Risk 813 %		AVR	100
Sight Distance 450 ft Percent Decision Site Distance 100 %		SIGHT DISTANCE	3
Roadway Width 48 ft		ROADWAY WIDTH	2
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1		CASE 1	
Structural Condition D [C]/F R [A]	Toppling	STRUCT COND	81
Rock Friction R I [U] P C - S		ROCK FRICTION	9
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 3 ft ft/yd^3	Up to 8 yd^3	BLOCK SIZE	27
Climate Precipitation L M [H] Freezing Period N [S] L Water on Slope N I [C]		CLIMATE	50
Rockfall History F O M [C]		ROCKFALL HISTORY	75
COMMENTS: History of accidents. Road patrols required year round.		TOTAL SCORE	547