Rockfall Hazard Rating System

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Many miles of highway pass through terrain with adjacent rock slopes that are subject to rockfall, which is due in part to construction practices in the past that relied on overly aggressive excavation techniques. Although these techniques facilitated removal of broken material, they commonly resulted in slopes more prone to rockfall. The Rockfall Hazard Rating System (RHRS) is intended to be a proactive tool that allows transportation agencies to rationally address their rockfall hazards instead of simply reacting to rockfall accidents. The RHRS provides a defensible, standardized way to spend the limited construction funds available by numerically differentiating the apparent risk at rockfall sites. The Oregon Department of Transportation (ODOT) began developing the RHRS in 1984. Funding from an FHWA-sponsored Highway Planning and Research (HPR) grant allowed ODOT to complete development of the system and test it at over 3,000 sites. Much of the RHRS's rating is subjective. Proper training in RHRS application is necessary to ensure the consistency of ratings between different raters. The responsibility for slope evaluations and design concepts should rest with experienced individuals. ODOT's staff of engineering geologists have demonstrated that reasonable and repeatable slope ratings can be achieved.

Transportation agencies are expected to provide a safe highway system for the public. This is not a simple task to accomplish, and it is made more difficult when highways pass through terrain requiring highway rock cuts. In mountainous states such as Oregon, many miles of roadway pass through steep terrain where rock slopes adjacent to the highway are common. Some of these man-made slopes are over 100 ft high and many are situated near the base of rugged natural slopes extending hundreds of feet further upslope, creating an inherent rockfall potential. This potential is compounded by the way our highway systems have evolved. Until recently, it was standard construction practice to use overly aggressive blasting and ripping techniques to construct rock slopes. This construction practice facilitated excavation and frequently resulted in slopes prone to rockfall. Where rockfall conditions exist, agencies are faced with the difficult task of reducing the risk of rockfall.

Oregon Department of Transportation (ODOT) management and legal counsel recognized the value of having a systematic way to set rockfall project priorities and allocate the limited repair funds. To be effective, the program would include an inspection of all rock slopes along the highway system to identify 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 ones presented the greatest risk. A rating system was needed to accomplish this.

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EVOLUTION OF ROCKFALL HAZARD RATING SYSTEM (RHRS)

Oregon began to discuss the need for an RHRS in 1984. As part of an initial literature search on the subject, a study by C. O. Brawner and Duncan Wyllie (*1*) was reviewed. It contained rating criteria and a scoring method that grouped rockfall sections into either A, B, C, D, or E categories based on the potential and expected effect of a rockfall event. ODOT adopted a similar assessment approach to the RHRS as part of the preliminary rating or rockfall areas.

In a subsequent study, Wyllie (*2*) outlined a more detailed rating procedure for prioritizing rockfall sites. Wyllie's method included specific categories for evaluation and scoring using an exponential scoring system. This became the prototype for Oregon's RHRS. The rating sheet format and the exponential scoring system were adopted. Some of the categories in the RHRS are similar, and others are new. All categories have been modified on the basis of experience in developing and applying the RHRS statewide over the past several years. Detailed narratives of the rating criteria were added to promote consistent application.

The final phase of RHRS development began in July 1989 when ODOT was selected to perform the HPR pooled-fund study. The principal objective of the study was to complete the development of an effective RHRS. Through full-state implementation, the RHRS was tested at over 3,000 sites. The narratives were finalized and forms and rating aids were developed. In order to streamline implementation of the system for other agencies, this information was documented in the RHRS User's Manual (*3*).

DESCRIPTION OF SYSTEM

The RHRS is a six-step process that allows agencies to actively manage the rock slopes along its highway system by providing a rational way to make informed decisions on where and how to spend construction funds. The process requires a greater commitment and focus on the rock slope issue than is commonly the case for many agencies. This commitment consists of additional working hours and dollars to complete the initial survey, to update the data base regularly, and to develop remedial programs aimed at reducing the rockfall risk at the worst sites. In addition, a properly trained and experienced staff is needed to perform the slope evaluations and to develop remedial designs.

The RHRS contains two phases of inspection: the preliminary rating phase, which is a part of the slope survey, and the detailed rating phase. This staged approach is the most efficient way to implement the RHRS in situations where an agency has responsibility for many slopes with a broad range of rockfall potential.

Slope Survey

The slope survey is an essential feature of the RHRS that allows an agency to accurately determine the number and location of its rockfall sites. The best way to approach the survey is without any preconceived notions of how many sites there are or where the most hazardous sites are located.

Accurate delineation of the rockfall section is important. For 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. Grouping separate cut slopes into one long section will diminish the value and the flexibility of the resulting data base. Grouping can occur later when project limits are defined during the project development process.

The maintenance person who is most knowledgeable about a section's rockfall history and the associated maintenance activities should accompany the rater because the past rockfall activity is an important indicator of what to expect in the future. As a better data base of rockfall occurrences is developed, more accurate conclusions for the rockfall potential can be made. It is important during this process to document the rockfall maintenance information, which is an important element of the preliminary rating.

Preliminary Rating

The purpose of the preliminary rating (Figure 1) is to group the rockfall sections inspected during the slope inventory into three broad, more manageable categories. Without this step, many additional hours would be spent applying the detailed rating at sites with only a low to moderate chance of producing a hazardous condition. This rating is a subjective evaluation of the rockfall potential and requires judgments by experienced, insightful personnel.

The RHRS is primarily concerned with the rockfall potential at a site. The criterion of the estimated potential for rock on the roadway is therefore the controlling element of this rating. Where clarification is needed, the historical rockfall activity is used as a modifier of the preliminary rating.

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 that it will reach the roadway—the risk that a hazardous situation will occur is nonexistent to low. As the rating increases to a B, the risk ranges from low to moderate. For A-rated sections, the risk ranges from moderate to high. Little is gained by adding intermediate categories. Consistency is most important. The ability and the comfort level in making these decisions improve with experience. All rockfall sections that receive an A rating should be photographed. These photographic records are useful when preliminary design concepts are discussed and especially useful for discerning changes in the slope that occur between reviews.

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

FIGURE 1 Preliminary rating system.

The preliminary evaluation is a critical step in the RHRS process, especially when there are a large number of slopes to consider. Initially, only the A-rated sections should be evaluated with the detailed rating system. This will economize the effort while directing it toward the most critical areas. The B-rated sections should be evaluated as time and funding allow. The C-rated sections receive no further attention and therefore are not included in the RHRS data base.

Detailed Rating System

Detailed rating, shown in Figure 2, is the third step in the RHRS. The detailed rating includes 10 categories that, when evaluated, scored, and totaled, allow an agency to numerically differentiate rock slopes from the least to the most hazardous. Slopes with higher scores present the higher risk. These 10 categories represent the significant elements of a rockfall section that contribute to the overall hazard. The four columns of criteria on the right correspond to logical breaks in the increasing risk associated with each category. Accordingly, the scores above each column increase from left to right exponentially from 3 to 81 points. An exponential system provides a rapid increase in score that distinguishes the more hazardous sites. The set scores are representative of a continuum of points ranging from 1 to 100. Using a continuum of points instead of only the set points listed at the top of each column allows the rater flexibility in evaluating the relative impact of conditions that are extremely variable.

To assist with scoring, the RHRS User's Manual (*3*) includes a scoring graph for each category. A sample graph for slope height is shown in Figure 3. The curve on the graph is the plot of the function $y = 3^x$, which defines the exponential scoring system used for all categories. The graph relates the category evaluation to an appropriate score. Even with subjective categories such as ditch effectiveness, the graph is quite useful in assigning a score to a condition that falls somewhere between the described benchmarks. 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 presented in Table 1.

Before decisions can be made on how to score a rockfall section, the criteria for each category must be well understood and carefully considered. To aid in understanding, narratives for each category are included. These narratives are based on extensive field testing of the system. Some categories require a subjective evaluation, whereas others can be directly measured and then scored. Along with the following category descriptions, sample ratings are provided.

Slope Height

Slope height represents the vertical height of the slope, not the slope distance. Rocks on high slopes have more potential energy than those on lower slopes, and therefore present a greater hazard and receive a higher rating. This measurement, obtained using the relationships shown in Equation 1 (Figure

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

FIGURE 2 Summary sheet of the Rockfall Hazard Rating System (RHRS).

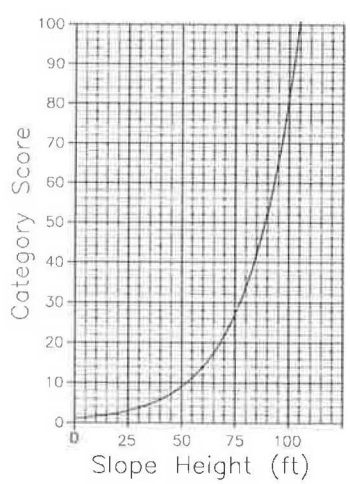


FIGURE 3 Sample scoring graph.

4), is to the highest point from which rockfall is expected, including the natural slope above the cut slope. 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 the problem. To further minimize error, the elevations of the points that define the distance X should be as equal as possible. The designation edge of pavement (EP) should be used only as a general guide. However, this measurement will also be useful in rating Category 5: Roadway Width.

Discussion The purpose of the 10 categories is to allow an agency to distinguish between rockfall sections with a relative rating. The slope height category is one that should be adjusted to fit local conditions in order to provide adequate score separation. In Oregon, all slopes that are 105 ft high or greater receive a score of 100 points.

TABLE 1 EXPONENT FORMULAS

Category	Formula (x)
Slope Height	$\frac{\text{Slope Ht. (ft.)}}{25}$
Average Vehicle Risk	$\frac{\text{\% Time}}{25}$
Sight Distance	$\frac{\text{120 - \% Decision Sight Dist.}}{20}$
Roadway Width	$\frac{\text{52 - Roadway Width (ft.)}}{8}$
Block Size	Block Size (ft.)
Volume	$\frac{\text{Volume (cu. ft.)}}{3}$

Sample The determined slope height is 40 ft. Using the scoring graph shown in Figure 3, this corresponds to a slope height score of 6 points.

Ditch Effectiveness

The effectiveness of a ditch is measured by its ability to restrict falling rock from reaching the roadway. The rater should consider several factors in estimating ditch effectiveness: (a) slope height and angle; (b) ditch width, depth, and shape; (c) anticipated volume of rockfall per event; and (d) 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. Scoring should be consistent with the following descriptions:

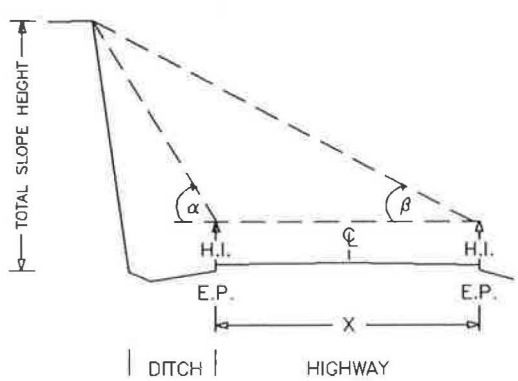
- **Good catchment, 3 points**—all or nearly all falling rocks are retained in the catch ditch.
- **Moderate catchment, 9 points**—falling rocks occasionally reach the roadway.
- **Limited catchment, 27 points**—falling rocks frequently reach the roadway.
- **No catchment, 81 points**—no ditch or totally ineffective ditch. All or nearly all falling rocks reach the roadway.

Sample The slope is 40 ft high and is cut on a 0.25:1 slope. The existing ditch is narrow, approximately 6 ft wide. Halfway up the slope is an irregular bench about 2 ½ ft wide that slopes toward the highway at about 60 degrees. The majority of the rockfall originates from the upper third of the slope. Falling rocks tend to stay in the ditch unless they hit the intermediate slope bench, which causes much of the rock to be directed onto the paved roadway. This is apparent from the distressed nature of the pavement that has been damaged by rockfall impacts. The maintenance person indicated that regular road patrols are necessary to keep the roadway clear. Because of the slope irregularity, the ditch provides limited catchment, and a score of 70 points is assigned.

Average Vehicle Risk (AVR)

AVR measures the percentage of time that a vehicle will be present in the rockfall hazard zone. The percentage is obtained by using a formula as shown in Equation 2, based on slope length, average daily traffic (ADT), and the posted speed limit at the site. A rating of 100 percent means that on average a car will be within the defined rockfall section 100 percent of the time. Where high ADTs or longer slope lengths exist, values greater than 100 percent will result and this means that at any particular time more than one car is present within the measured section. The result directly relates to the significance of the route and the potential hazard by approximating the likelihood of a vehicle's being present and thus being involved in a rockfall incident.

$$\frac{\text{ADT (cars/day)} \times \text{slope length (miles)} / 24 \text{ (hours/day)}}{\text{Posted speed limit (mph)}} \times 100\% = \text{AVR} \qquad (2)$$



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

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

FIGURE 4 Slope height diagram.

Sample Based on an ADT of 5,200 vehicles per day, a slope length of 0.09 mil, and a posted speed limit of 30 mph, the calculated AVR is 65 percent. This correlates to a score of 17 points.

Percent of Decision Sight Distance

The decision sight distance (DSD) is the length of roadway (in feet) that a driver must have to make a complex or instantaneous decision. The DSD is critical when obstacles on the road are difficult to perceive or when unexpected or unusual maneuvers are required. Sight distance is the shortest distance along a roadway for which a 6-in. object is continuously visible to the driver. Normally an object will be most obscured when it is located just beyond the sharpest part of a curve. The sight distance can change appreciably throughout a rockfall section. Horizontal and vertical highway curves, along with obstructions such as rock outcrops and roadside vegetation, can severely limit a driver's ability to notice a rock in the road. The DSDs recommended by the American Association of State Highway and Transportation Officials (AASHTO) are presented in Table 2. The relationships between DSD 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 in Table 2 represent the low design value and the speed limit posted for the rockfall section should be used.

Once determined, these two values can be substituted into Equation 3 to calculate the percent of DSD:

$$\frac{\text{Actual sight distance}}{\text{Decision sight distance}} \times 100\% = \%\ \text{DSD} \qquad (3)$$

Sample The posted speed limit is 30 mph for a curved section of highway. The recommended sight distance for this speed is 450 ft. The actual sight distance is impaired by the rock slope on the inside of the curve in conjunction with a series of power poles and roadside vegetation. The measured sight distance is 315 ft. Substituting these values into the formula, the percent of DSD is 70, which correlates to a score of 16 points.

Roadway Width

Roadway width is measured perpendicular to the highway centerline from edge of pavement to edge of pavement (EP to EP). This measurement represents the available maneuvering room to avoid a rockfall, and should be the minimum width when roadway width is not constant. On divided roadways only the paved portion available to the driver should be measured.

TABLE 2 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

Sample The paved roadway includes two 12-ft lanes, a 2-ft shoulder adjacent to the cut slope, and a 4-ft shoulder on the opposite side for a total of 30 ft, which correlates to a score of 21 points.

Geologic Character

A slope's geologic conditions are evaluated with this category. Since the conditions that cause rockfall generally fit into two categories, Case 1 and Case 2 rating criteria have been developed. Case 1 is for slopes where joints, bedding planes, or other discontinuities are the dominant structural features. Case 2 is for slopes where differential erosion or oversteepening is the dominant condition. The rater should use the case that best fits the slope. 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.

Case 1: Structural Condition "Adverse" as used here involves considering such characteristics as rock friction angle, joint filling, and the effects of water, if present, as well as the joint's spatial relationship to the slope. Adverse joints are those that allow block, wedge, planar, or toppling failures. "Continuous" refers to joints longer than 10 ft.

- **Discontinuous joints, favorable orientation, 3 points**—slope contains jointed rock with no adversely oriented joints, bedding planes, etc.
- **Discontinuous joints, random orientation, 9 points**—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.
- **Discontinuous joints, adverse orientation, 27 points**—rock slope exhibits a prominent joint pattern, bedding plane, or other discontinuity with an adverse orientation. These features have less than 10 ft of continuous length.
- **Continuous joints, adverse orientation, 81 points**—rock slopes exhibits a dominant joint pattern, bedding plane, or other discontinuity with an adverse orientation and more than 10 ft long.

Case 1: Rock Friction Rock friction 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 microroughness of the surfaces. Macroroughness is the degree of undulation of the joint relative to the direction of possible movement. Microroughness is the texture of the surface. The rockfall potential is greater in areas where joints contain highly weathered or hydrothermally altered products, where movement has occurred causing slickensides or fault gouge to form, where open joints dominate the slope, or where joints are water filled. Noting the

failure angles from previous rockfalls on a slope can aid in estimating general rock friction along discontinuities.

- **Rough, irregular, 3 points**—the surface of the joints is rough and the joint planes are irregular enough to cause interlocking. This macro- and microroughness provide an optimal friction situation.
- **Undulating, 9 points**—macroroughness but without the interlocking ability.
- **Planar, 27 points**—macrosmooth and microrough joint surfaces. Friction is derived strictly from the roughness of the rock surface.
- **Clay infilling, or slickensides, 81 points**—low-friction materials, such as clay and weathered rock, separate the rock surfaces, negating any micro- or macroroughness of the joint planes. Slickensided joints also have a very low friction angle and belong to this category.

Case 2: Structural Condition Case 2 is used for slopes in which differential erosion or oversteepening is the dominant condition leading to rockfall. Because rockfall is caused by a loss of support either locally or throughout the slope, erosion features such as oversteepened slopes, unsupported rock units, or exposed resistant rocks on a slope may eventually lead to a rockfall event. Common slopes that are susceptible to this loss of support are layered units containing easily weathered rock that erodes, undermining more durable rock; talus slopes; and highly variable units such as conglomerates, mudflows, rock/soil slopes, etc., that weather and allow resistant rocks and blocks to fall as the matrix material is eroded.

- **Few differential erosion features, 3 points**—minor differential erosion features that are not distributed throughout the slope.
- **Occasional erosion features, 9 points**—minor differential erosion features that are widely distributed throughout the slope.
- **Many erosion features, 27 points**—differential erosion features that are large and numerous throughout the slope.
- **Major erosion features, 81 points**—severe cases such as dangerous erosion-created overhangs or significantly oversteepened soil/rock slopes or talus slopes.

Difference in Erosion Rates The rate of erosion on a Case 2 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 human actions, should be considered. The degree of hazard caused by erosion and also the score given this category should reflect how quickly the erosion is occurring; the size of rocks, blocks, or units being exposed; the frequency of rockfall events; and the amount of material released during the event.

- **Small difference, 3 points**—erosion features take many years to develop. Slopes that are near equilibrium with their environment are covered in this category.
- **Moderate difference, 9 points**—the difference in erosion rates allows erosion features to develop over a few years.
- **Large difference, 27 points**—the difference in erosion rates is such that noticeable changes in the slope develop annually.
- **Extreme difference, 81 points**—the difference in erosion rates allows rapid and continuous development of erosion features.

Sample The slope consists of basalt and there is a greater density of natural joints and blast-induced fractures in the upper part of the slope. The joints and fractures are the dominant structural features of the slope and therefore a Case 1 condition exists. The fracture pattern is random and the joints are discontinuous. On this basis the slope receives a structural condition score of 9 points.

Extensive hydrothermal alteration has occurred along the natural joints leaving a ¼-in. clay coating on many surfaces. The surfaces of the blast-induced fractures are fresh and undulating. Failure of blocks along the clay coatings creates unsupported slope conditions leading to other block failures. Because not all surfaces are clay-coated, a score of less than 81 points is appropriate and a score of 60 points is assigned.

Block Size or Volume of Rockfall per Event

If individual blocks are typical of the rockfall, the block size should be used for scoring. If a mass of blocks tends to be the dominant type of rockfall, the volume per event should be used. A decision on which one 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.

Sample The rockfalls tend to be individual blocks. The block size is consistently in the 3½-ft size range. A block size score of 47 points is determined.

Climate and Presence of Water on Slope

Water and freeze-thaw cycles contribute to the weathering and movement of rock materials. If water is known to flow continually or intermittently from the slope, the slope is rated accordingly. Areas receiving less than 20 in. per year are low-precipitation areas. Areas receiving more than 50 in. per year are considered high-precipitation areas. The impact of freeze-thaw cycles can be interpreted from knowledge of the 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.

Discussion Information on average temperatures and length of freezing periods can be obtained from National Oceanic and Atmospheric Administration (NOAA) climatological publications (5). The criteria used for this category should

be adjusted to fit local conditions to ensure proper score separation.

Sample This area receives 60 in. of precipitation annually and experiences severe winter conditions for 3 to 4 months per year. Water on the slope is not an issue. A score of 81 points is given because of the heavy rainfall and long freezing periods.

Rockfall History

Historical information is best obtained from the maintenance personnel responsible for the slope because they directly represent the known rockfall activity at the site. 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. Historical information is an important check on the potential for future rockfalls. If the score given a section does not compare with the rockfall history, a review of the rating is advisable.

- **Few falls, 3 points**—rockfalls only occur a few times a year or less, or only during severe storms. This category is also used if no rockfall history data are available.
- **Occasional falls, 9 points**—rockfall occurs regularly and can be expected several times a year and during most storms.
- **Many falls, 27 points**—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 and are not a significant problem during the rest of the year. This category may also be used where severe rockfall events have occurred.
- **Constant falls, 81 points**—rockfalls occur frequently throughout the year. This category is also used for sites where severe rockfall events are common.

Sample This area was identified by the maintenance personnel as being a seasonal rockfall problem. Road patrols are required daily during the winter and spring to keep the roadway clear. The level of rockfall at this site is assigned a score of 35 points.

Preliminary Design and Cost Estimates

It is important when planning highway construction projects to properly scope the desired result, which determines the project limits, the estimated construction costs, the right-of-way needs, etc. Trying to retrofit a different, more appropriate rockfall design after these items have been established is frustrating and can be completely unworkable.

Therefore, the fourth step of the RHRS process requires a preliminary design and cost estimate to be included as part of the RHRS data base. With this information, rockfall projects can be properly funded and developed. Value-engineering the level of effort and the cost associated with a particular rockfall section can help match the result to the need. A systematic method for analyzing the possible response alternatives has been described by Keaton and Eckhoff (*6*).

Covering the field of rock mechanics is beyond the scope of this paper. An excellent reference on the subject for the practitioner is an FHWA publication (*7*). Because experience is the best test of the reasonableness of a rockfall remedial design, the value of having skilled personnel in this area cannot be overly stressed. The gaps in the understanding of the mechanical properties of rock masses are still too large to rely strictly on an analytical approach. This is not to say that all of the analytical tools available will not be used, if needed. However, at this stage the goal is to provide an appropriate method to deal with the rockfall problem that can later be refined by more detailed investigation and analysis.

More than one design approach to reduce the rockfall risk should be considered for each site. A hazard reduction measure can vary from a limited-duration improvement such as slope scaling to a more positive step such as installing wire mesh to control the descent of falling rocks. Frequently, a combination of many techniques will work best.

The rockfall design cost estimate is strictly for rockfall remedial measures. A project may eventually include widening pavement, installing guardrail, adding a structural pavement overlay, etc. These actions as well as mobilization, engineering, and contingencies, etc., are not included as part of the RHRS cost estimate. Later, when different rockfall sites and the cost to deal with them are compared, these additional cost items will not interfere.

Project Identification and Development

The true benefit of implementing the RHRS—a reduction in the systemwide rockfall potential—will be realized once rockfall remedial projects are developed from the resulting data base. The following are ways to use the RHRS to identify and advance projects for construction.

1. Projects can be advanced on the basis of score. This is the most obvious use of the system. Because the most hazardous slopes are those at the top of the list, projects would be funded for construction as funds become available.
2. Projects can be advanced on the basis of their score relative to their estimated construction costs. In effect, a modification of the benefit-cost method is used. The preliminary cost estimate for the top-rated slopes is divided by the RHRS score and a list is generated with the lowest ratios of dollars to RHRS points at the top. Projects developed from this list would provide the greatest systemwide hazard reduction with a fixed investment.
3. Projects can be developed on the basis of the remedial approach. Rockfall sections containing similar construction features would be grouped into a single project. An example would be to take a length of highway and combine into one project all of the sections that include slopes screening. By doing this, a larger quantity would be contracted and could result in more straightforward, more easily managed contracts with lower unit bid prices.
4. Projects can be developed on the basis of proximity of rockfall sites along a section of roadway. A larger contract could be let because the rockfall sites have been identified and remedial measures properly determined. An example of this would be where all rated slopes along a 20-mi stretch of roadway are grouped into one project.

All these approaches rely on the data from the RHRS data base generated from implementation and periodic updates.

Annual Review and Update

The final step of the RHRS is to perform an annual review of all rated slopes. Natural conditions can change unexpectedly and these changes are often difficult to discern. Photographs taken during previous inspections will help identify changes. Any newly constructed slopes should also be evaluated and if necessary added to the RHRS database.

Eventually, all slopes in the RHRS data base should be evaluated with the detailed rating. Much of this work could be accomplished throughout the year by personnel commuting to and from other job-related responsibilities. The annual review and update would protect an agency's investment and maintain the value of the RHRS data base. Once all slopes are 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.

SYSTEM LIMITATIONS

The RHRS provides agencies with a method to address their rockfall problems by providing a relative rating among slopes. For the most part, this relative rating is subjective. The slope evaluation process is as straightforward as possible, however, there is still a range of values a slope could receive. Much depends on the abilities of the raters and how consistently they interpret and apply the rating criteria. Even though one slope receives a score of 700 and another receives a score of 600, both slopes have the potential of releasing rock onto the roadway.

Agencies will always be expected to react to rockfall accidents no matter where a particular section appears on the RHRS priority list, but the tendency to overreact should be resisted. Sites where an accident has occurred should be reevaluated with 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 new potential relative to that on the other sites.

BENEFITS

It is not reasonable to expect an agency to have enough funds necessary to deal with all safety-related issues at once. However, it is necessary to have a system in place by which projects are identified and developed as funding is made available. ODOT experience has been that this is legally defensible. The use of the RHRS as a defense has not been tested in Oregon to date. However, Oregon has for many years had a priority list for developing rockfall construction projects. The sites listed are those identified as having an accident history or excessive maintenance costs, or both. The list generally contains only 100 sites and is not based on the rockfall potential but on the rockfall history. The sites are prioritized on the basis of a cost-benefit analysis. Even though ODOT had a definite, planned approach to deal with rockfall sites as funds became available, litigations brought against the state because of rockfall accidents either were settled out of court or were found favorably to the state. ODOT believes that having a more comprehensive, state-of-the-art process for developing the priority list will serve better.

CONCLUSION

ODOT engineering geology staff have spent many hours designing, testing, and redesigning the RHRS system. The process has been manageable, and was completed while Staff maintained a busy, normal workload. It was found beneficial to have the engineering geologists responsible for creating and maintaining the RHRS database.

ODOT's experience with the RHRS has been favorable. Management now has a uniform process that can help make practical decisions on where to allocate money for rock slope projects and they welcome having quality information to use in this area of project development. The agency believes that the issue of public safety is being properly addressed and that greater legal protection is afforded the agency by having the RHRS in place.

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