REPORT ON THE "SHAKEDOWN" TEST OF OREGON'S ROCKFALL HAZARD RATING SYSTEM

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16. Abstract

Oregon Rockfall Hazard Rating System (RHRS) was field tested at over 50 locations statewide to determine where clarification and improvements to the system were needed. Field use of the system demonstrated many areas where refinements were valuable. These changes along with revised narratives explaining the various rating criteria have been incorporated into the new RHRS.

This opportunity confirmed the usefulness of the system as a prioritization tool. Once completed through full scale implementation, the RHRS will allow States to systematically evaluate the rockfall hazards along their highways. This will permit them to prudently direct project funding at their most potentially dangerous sites.

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PURPOSE

The purpose of the "shakedown" test was to determine what improvements could be made to the Rockfall Hazard Rating System (RHRS) based on actual field use. This involved applying the system to approximately 50 slopes statewide. Utilizing ODOT's staff of engineering geologists, we found that, as we gained experience using the system, changes were necessary. This report will summarize the test results and more importantly describe the resulting improvements to the RHRS.

BACKGROUND INFORMATION

As in many other states, the original method ODOT used to identify rockfall projects relied primarily on the costs associated with the accident history and the annual maintenance relative to the estimated construction costs. A copy of this benefit/cost ratio methodology and the resulting rockfall priority list is included in Appendix A. By its nature, this type of system is a reactive prioritization technique.

The emphasis with this system is necessarily placed on those sections where an accident has already taken place. This may or may not reflect the potential for future rockfall events. The annual maintenance cost at a particular rockfall section generally represents the cost to clean out the catch ditch. If an adequately designed catch ditch performs well but needs regular cleaning, the maintenance cost may be high but the hazard to the motoring public is low. This would indicate that these two items are not sufficient by themselves to develop a rockfall priority list. In addition, this technique relied on historical information provided by a very diverse group of sources: maintenance crews, law enforcement personnel, the general public, traffic engineers, etc. These people were not adequately trained to systematically document or evaluate rockfall events.

The benefit/cost ratio technique is not without its good points. It does provide a means of obtaining the greatest return on the repair investment. However, to be of any real value, it must be applied to the most hazardous rockfall sections.

ODOT's management as well as its legal counsel felt that a proactive element should be added to the program in order to provide a "rational" means of prioritizing projects and allocating scarce repair funds. After many discussions, we determined that such a program must include an inspection of rock slopes on the State's highway system to determine where rockfall would most likely effect the roadway. Once identified, these sections should be rated relative to each other to determine which were the most hazardous. To perform this task a rockfall hazard rating system needed to be developed.

EVOLUTION OF THE RHRS

The responsibility for Oregon's highway system is divided, geographically, into 5 Regions. Early in 1985, one of the Regions undertook the task to inventory their highways to document where potential rockfall areas existed. This was a very ambitious effort that gathered and documented a great deal of valuable information. The data included:

1. Rockfall locations
2. Slope height
3. Slope angle
4. Fallout dimensions
5. Material size
6. Type of rockfall
7. Rockfall history
8. Short and long term correction measures
9. Photographs

This study laid the foundation for our rating system but it did not provide a relative rating between the rockfall sections.

As part of our literature search, we located a 1975 paper written by C. O. Brawner and Duncan Wyllie (1). It contained a rating criteria and scoring method that grouped rockfall sections into either A, B, C, D, or E categories based on the potential for and the expected effect of a rockfall event. We have adopted a similar assessment approach in performing our preliminary rating of rockfall areas.

In a 1987 paper by Wyllie (2), he outlined a more comprehensive system for prioritizing rockfall sites. This rating method included specific categories and descriptions that needed to be evaluated and then scored using an exponential scoring system. This system became the prototype of our RHRS. We adopted the rating sheet format, the exponential scoring system and six of his rating categories. We modified four others and added six of our own.

The RHRS contains two phases of inspection, the initial assessment phase (preliminary rating) and the detailed rating phase. The first phase consists of the preliminary rating of all sections along a State's highway system where rockfall potential exists. The assessment (Figure 1) is performed by an engineering geologist and whichever maintenance person is most knowledgeable about the rockfall history along that section of highway. Presently, we rely on the expertise and experience of the raters to determine this relativistic rating. Specific guidelines for applying the preliminary rating system are being considered.

PRELIMINARY RATING SYSTEM

CRITERIA / CLASS	A	B	C
HISTORICAL ROCKFALL ACTIVITY	High	Moderate	Low
ESTIMATED POTENTIAL FOR ROCKFALL	High	Moderate	Low
ESTIMATED POTENTIAL FOR ROCK ON ROADWAY	High	Moderate	Low

FIGURE 1

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 allows. The "C" rated sections will receive no further attention. In Oregon, we estimate that approximately 1500 areas will be rated by the initial assessment. Of these only about 300 will likely receive an "A" rating.

Once the prototype of the detailed rating system (Figure 2) was developed, a training and debugging session was held in November, 1987. The Geology staffs from each of the 5 Regions were brought in for a 2-day training session, which included a one day orientation meeting to introduce the system and a one day hands-on field trip. The purpose of the field session was twofold. It provided a chance for everyone to practice using the system and to evaluate it. This test group provided information on several important aspects:

1) Could several different raters achieve uniform results?
2) Was the system understandable ~~and easy~~ to use?
3) Did the narrative adequately explain each item to be rated?
4) Did the scores accurately assess the rockfall hazard of the slope?

In general the results were very positive. However, as a result of this session, several modifications were made to the narrative to enhance it and make it clearer.

ROCKFALL HAZARD RATING SYSTEM (PROTOTYPE)

RATING	POINTS 1	POINTS 3	POINTS 9	POINTS 27	POINTS 81
SLOPE HEIGHT	< 25 FT	25 TO 50 FT	50 TO 75 FT	75 TO 100 FT	> 100 FT
SLOPE LENGTH	< 100 FT	100 TO 500 FT	500 TO 1000 FT	1000 TO 1500 FT	> 1500 FT
SLOPE CONTINUITY	No launching features	Possible launch features	Some minor launch features	Many launching features	Major rock launching features
AASHTO DECISION SITE DISTANCE	Good site distance Greater than design range	Adequate site distance Within design range	Moderate site distance 80-100% of low design value	Limited site distance 50-80% of low design value	Very limited site distance < 50% of low design value
ROADWAY WIDTH INCLUDING SHOULDERS PAVED & UNPAVED	> 44 feet	44 - 30 feet	30 - 25 feet	25 - 20 feet	< 20 feet
TRAFFIC ADT	Very light 0 - 500	Light 500 - 2000	Moderate 2000 - 5000	Heavy 5000 - 10000	Very heavy/ continuous 10000 +
DITCH DIMENSIONS	Meets Ritchie criteria	Adequate width, Inadequate depth	Moderate catchment	Limited catchment	No catchment
GEOLOGIC CHARACTER — CASE 1 — STRUCTURAL CONDITION	Massive, no fractures dipping out of slope	Discontinuous fractures, favorable orientation	Discontinuous fractures, random orientation	Discontinuous fractures, adverse orientation	Continuous fractures, adverse orientation
GEOLOGIC CHARACTER — CASE 1 — ROCK FRICTION	Rough, Irregular	Undulating	Planar	Smooth, Slickensided	Clay, gouge infilling
GEOLOGIC CHARACTER — CASE 2 — STRUCTURAL CONDITION	No differential erosion features	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
GEOLOGIC CHARACTER — CASE 2 — DIFFERENCE IN EROSION RATES	No difference	Small difference	Moderate difference	Large difference, favorable structure	Large difference, unfavorable structure
BLOCK SIZE	< 6 IN	6 to 12 IN	1 to 2 FT	2 to 5 FT	> 5 FT
QUANTITY OF ROCKFALL/EVENT	< 1 cubic foot	1 cubic foot to 1 cubic yard	1 to 3 cubic yards	3 to 10 cubic yards	> 10 cubic yards
PRECIPITATION/ CLIMATE	Low precipitation no freezing periods	Moderate precipitation or some freezing periods	Moderate precipitation and some freezing periods	High precipitation or long freezing periods	High precipitation and long freezing periods
ROCKFALL HISTORY	No history	Few falls	Occasional falls	Many falls	Constant falls
AVERAGE YEARLY MAINTENANCE COSTS	$0 - $500	$500 - $2000	$2000 - $10000	$10000 - $25000	$ 25000 +

FIGURE 2

The next phase of the system development was a series of meetings. At these "brainstorming sessions" we continued to refine the RHRS and began to address the issues involved in implementation of the system. These issues included funding, and the time and manpower needs imposed by the system. To that point we had spent nearly $80,000 on earlier inventory efforts and development of the system. As a result of these discussions, we began to look for additional funding and management support that would allow us to continue development and eventually lead to full-scale implementation of the RHRS. Subsequently, we were able to acquire an additional $30,000 ($10,000 from ODOT's Research Section and $20,000 from the FHWA's Office of Implementation) in March, 1988 to continue our shakedown effort.

"SHAKEDOWN" TEST

In May, 1988, we began a series of field tests and evaluation meetings to see how well the concept and the format of the RHRS actually worked in the field. Each Geology unit would use the system to rate a few slopes in their Region, then we would meet to discuss the merits and shortcomings of the system. This process resulted in many modifications and improvements.

Data

The table on the following page summarizes the data acquired during the shakedown test. It lists 51 sections that were rated with the greatest hazard (highest score) at the top. The fifth column lists how these sections rated as a result of the benefit/cost ratio prioritization method. You can see that here is a tendency for an inverse relationship to exist between the priority ratings of the RHRS and the ratings of the old benefit/cost ratio system. This is because the RHRS is a hazard rating which is not directly affected by costs whereas the benefit/cost ratio system rating is strongly affected by the cost to fix the rockfall problem. This demonstrates that the highest hazard sites can rate low if they have high mitigation costs. Conversely, the low hazard sites can tend to rate high if they have low mitigation costs. Our experience with rockfall mitigations indicates that the inverse relationship found in the shakedown study is accurate. By nature hazardous rockfalls tend to be expensive to fix.

Since the primary objective of developing a rockfall priority list is hazard reduction, we feel that the proactive approach is far more beneficial. It provides a sound data base from which economic decisions can be made.

PRIORITIZATION OF "SHAKEDOWN PHASE" TEST RATINGS (10/88)

RANK WITHIN TEST GROUP	HIGHWAY NUMBER & NAME		MILEPOST	SCORE	ORIGINAL RANKING AS OF 9/87	ESTIMATED COST OF MITIGATION
1	16	Santiam	78.75 - 79.46	633	- -	- -
2	162	North Santiam	39.66 - 40.15	633	85	- -
3	2	Columbia River	197.62 - 203.22	549	13	$ 1.2 Mil
4	37	Wilson River	31.25 - 31.50	539	- -	$ 1.3 Mil
5	26	Mt. Hood	49.10 - 49.37	520	82	$ 900 K
6	9	Oregon Coast	40.57 - 40.99	516	84	- -
7	9	Oregon Coast	40.90	505	84	$ 33 K
8	11	Enterprise-Lewiston	0.00 - 5.00	495	9	$ 500 K
9	18	Willamette	23.40 - 23.80	495	- -	$ 625 K
10	2	Columbia River	58.61 - 58.91	471	3	$ 500 K
11	125	Crown Point	4.30 - 4.48	449	99	$ 468 K
12	2	Columbia River	52.12 - 52.70	444	3	$ 3.9 Mil
13	162	North Santiam	49.90 - 50.00	433	- -	- -
14	162	North Santiam	44.13 - 44.36	426	75	- -
15	1E	East Pacific	12.62 - 12.94	409	71	$ 1.7 Mil
16	2	Columbia River	54.48 - 54.90	408	3	$ 63 K
17	35	Coos Bay - Roseburg	48.80	408	59	- -
18	162	North Santiam	40.15 - 40.28	401	- -	- -
19	9	Oregon Coast	41.19 - 41.32	380	- -	- -
20	18	Willamette	19.80 - 20.20	379	- -	$ 425 K
21	16	Santiam	78.52 - 78.68	373	- -	- -
22	22	Crater Lake	37.18	363	46	$ 224 K
23	2	Columbia River	49.63 - 50.25	309	3	$ 690 K
24	9	Oregon Coast	131.65 - 131.86	307	- -	- -
25	73	North Umpqua	48.50	307	- -	$ 150 K
26	73	North Umpqua	48.50	301	- -	$ 150 K
27	73	North Umpqua	42.90	301	- -	$ 30 K
28	2	Columbia River	55.09 - 55.62	291	- -	$ 121 K
29	163	Silver Falls	37.96	291	38	- -
30	2	Columbia River	37.73 - 37.85	289	3	$ 596 K
31	415	Dooley Mountain	23.65 - 24.25	289	4	$ 50 K
32	215	Clear Lake-Belknap Springs	6.36 - 6.70	279	- -	- -
33	45	Umpqua	29.00	262	- -	- -
34	163	Silver Falls	38.00	253	- -	- -
35	12	Baker - Copperfield	27.85 - 27.98	234	11	$ 126 K
36	35	Coos Bay - Roseburg	8.30	219	5	$ 140 K
37	73	North Umpqua	40.00 - 40.05	199	- -	$ 30 K
38	73	North Umpqua	51.00	199	- -	$ 30 K
39	6	Old Oregon Trail	259.35	199	72	$ 332 K
40	6	Old Oregon Trail	318.00	199	10	$ 73 K
41	73	North Umpqua	51.00	193	- -	$ 30 K
42	28	Pendleton - John Day	52.30	181	16	$ 50 K
43	12	Baker - Copperfield	33.00 - 33.10	172	7	$ 210 K
44	215	Clear Lake-Belknap Springs	6.25 - 6.36	171	- -	- -
45	73	North Umpqua	44.90 - 45.00	169	- -	$ 40 K
46	5	John Day	103.80 - 104.20	163	1	$ 175 K
47	12	Baker - Copperfield	34.10	163	7	$ 168 K
48	351	Joseph - Wallowa	2.00 - 5.45	163	- -	$ 200 K
49	16	Santiam	79.49 - 79.53	157	- -	- -
50	12	Baker - Copperfield	26.60 - 26.73	139	11	$ 112 K
51	10	Wallowa Lake	40.75	95	14	$ 14 K

TABLE 1

Changes To RHRS

The following section is a category by category summary of the modifications that were made to the RHRS during the shakedown phase.

1. Slope Height - Initially (at the start of the shakedown), we used >45 ft. to define the 81-point break in this category. Once in the field, we quickly realized that this resulted in too many of our slopes placing very high in this category. To be effective, the rating criteria needs to form logical breaks in encountered conditions. Thus, we increased the 81-point break in this category to >100 ft.

We also expanded the narrative to emphasize that this measurement was to the highest point from which rockfall is expected not just to the top of the cut. Some people were tending to analyze only the highway cut slope without considering the rockfall potential from outcrops above the cut.

2. Slope Length - We had a similar problem with this category which defined the 81-point break as >200 ft. As with the Slope Height, we had to expand our parameters so that the 81-point category criteria was increased to >1500 ft. to prevent a very large percentage of our cuts from receiving 81 points.

The narrative for this section evolved to explain the need for measuring only the length of slope that is involved in the rockfall problem. People tended to measure the length of cuts or even long sections of road that had gaps where no rockfall occurred.

Eventually we eliminated this as a separate category by combining it with the traffic ADT to form the "Average Occurrence of Vehicles in the Rockfall Zone" category. See that category for more information.

3. Traffic ADT - As a result of the shakedown, this category has been combined with the Slope Length category to form the "Average Occurrence of Vehicles in the Rockfall Zone" category. See that category below.

4. Average Occurrence of Vehicles in the Rockfall Zone - This is a new category that combines the highway's average daily traffic (ADT), the length of the rockfall section, and the posted speed limit to derive the average percent of time that a vehicle is present within the rockfall section. Another way of looking at this is that it shows how many vehicles are in the rockfall section at any one time. This directly relates to the potential hazard as well as the significance of the route. While the information from the original two categories was important, reporting it just as

data didn't meet the purpose of the rating system. By combining it into this formula we are able to produce a rating that actually helps reflect the hazard at the site.

5. Slope Continuity - Even with the narrative this category requires quite a bit of judgement by the rater and has tended to be a topic of discussion throughout the shakedown phase. The narrative has been clarified to provide as much guidance as possible while retaining enough flexibility to allow a certain amount of decision making by the raters. We have found that frequent dialog between the raters about how they're scoring this category, is the most effective way to maintain uniformity with the scoring. The training sessions where we all went to the field together were also very helpful in developing a uniform approach to this category.

6. Ditch Effectiveness - Originally, this category was called "Ditch Dimensions," where the dimensions of the existing ditch were compared to those recommended by the ODOT Rock Slope Design Policy. This document is contained in Appendix B. In this policy the Ritchie Criteria, developed by the Washington Department of Transportation, is used to design rock fallout areas. Scoring criteria was based on what percentage of the recommended ditch was present. After observing many slopes during the shakedown phase we found that in fact for some slope conditions ditches that were far below the Cut Slope Policy parameters were actually very effective at retaining rockfall while in some cases just the opposite was the case. Therefore, scoring based on these parameters wasn't an accurate reflection of the rockfall hazard. This category now rates the effectiveness of the ditch in restricting falling rocks from reaching the roadway.

7. AASHTO Decision Site Distance - The method for measuring this category was taken from Table III-3 of "AASHTO's Policy on Geometric Design of Highways and Streets" (3). However, as we began to rate slopes, we found that determining the actual design speed for a site, as recommended by the AASHTO Table, was difficult in most cases. Therefore, we decided to substitute the posted speed limit of the site for the design speed. We feel this still provides us with a relative rating of the site distance hazard that can be compared with the ratings at other sites.

8. Roadway Width Including Paved Shoulders - This category originally included paved and unpaved shoulders. It was meant to measure how much room was available for a car to maneuver around a rock in the road. As the shakedown progressed we found it was difficult to get uniform estimates about what was unpaved shoulders and what was unmaneuverable side slopes. Consequently, to obtain uniformity we revised the category to include only paved shoulders.

9. Geologic Character - Definitions of terms used for the "Geologic Character" category are contained in ODOT's Soil and Rock Classification manual (5). Our prototype system had geologic character divided into 2 separate rating categories. Case 1 was used to rate slopes where the structural discontinuities in the rock were the primary cause of rockfall. Case 2 was developed to rate cuts where differential erosion of the slope materials was the cause of the rockfall problem. The rater was to use whichever case applied and if both conditions were present, use the worse case (highest score).

Through the course of our meetings we decided that the "Rock Friction" category was primarily related to Case 1 conditions so it was combined with this category. As a consequence, a second "modifier" category was added to Case 2 to maintain uniformity. This new category rated the relative difference in erosion rates on slopes where differential erosion features dominated the structural condition.

The shakedown phase was very important for this category because rating it draws heavily on the expertise of the rater. We spent many hours discussing this category and refining the narrative. The narrative for this section requires a delicate balance between giving the rater enough guidance while still allowing them enough freedom to use their expertise.

10. Block Size/Quantity of Rockfall per Event - These were originally two separate rating categories. After the shakedown we decided to combine them into one, either/or category. Both are important criteria but it was felt that rating both gave them too much influence on the total slope rating. Also in some rockfall situations, such as where a single large block falls, we were in essence rating the same thing twice. We combined them which allows the rater to evaluate both but then only use the highest of the two scores as the rating.

11. Climate and Presence of Water on Slope - Throughout the shakedown phase we have had frequent discussions on how we could rate the influences freeze-thaw cycles and hydrostatic pressure have on slope stability. We adopted a rating based on the amount of precipitation and occurrence of freezing periods because these are measurable quantities that are directly related to these features. Information on average temperatures and length of freezing periods can be obtained from NOAA Climatological Publications (5).

Our debate over how to rate the hydrological conditions on a slope centered around whether or not water flowing from or on the slope was indicative of a good or bad condition. It can be correctly argued that when water is confined within a slope, a worse case (elevated groundwater levels) might exist. While a slope with free flowing water may be actually draining the slope thus improving overall stability. Since information on where water levels are is difficult to obtain, we decided that it would be impractical to use that criteria for our rating. Also, because water flowing on a slope does promote erosion, we decided that this was a worse condition than when no water is present. To allow for this condition, we added another scoring criteria to this category that ranged from no water on the slope to continual water on the slope.

12. Rockfall History - As we gained more data and experience about the variety of rockfall histories, we were able to design the rating to better evaluate these histories. We found there was a need for a scoring category between "many falls", which was the 27-point category, and "constant falls" (81-point category). The narrative for the 27-point category was changed to rate conditions where constant rockfall occurs on a seasonal basis. Criteria for what was the 3, 9, and 27 point categories was rewritten into the 3 and 9 point slots in the new system.

13. Average Yearly Maintenance Costs - This original rating category was deleted near the end of the shakedown. In many cases, maintenance costs are associated with clearing rockfall from fallout areas. If rock is contained in the fallout areas, it is not a hazard. The ratings in this category tended to be skewed towards economics rather than rockfall hazard. We still advocate gathering this data but we feel it isn't a valid criteria for rating potential hazard. We now suggest that this data be used as a check of the reported rockfall history. If rockfall related maintenance costs are high at a site, the rater should expect either a fairly high overall score or the presence of an effective catchment area.

. . .

Originally, we felt that each category should cover the complete range of natural conditions from the best to the worst. As a result of the shakedown test, our latest detailed scoring system no longer contains the 1-point (best case) category. It became obvious that the the preliminary assessment using the "A-B-C Rating System" should have already eliminated most slopes with these features. Part of the shakedown included rating slopes that would have recieved either a "B" or "C" rating. Even in these cases, we found that only rarely did we encounter cases that received 1-point scores. In the categories where these conditions might be encountered, we have shifted the scoring so that the 3-point category now covers them.

Prior to the RHRS developed at the end of the shakedown phase, all of our scoring was done with an exponential system where the score a category recieves rises quickly as the hazard increases. We used the exponential system because we felt that a straight numerical system wouldn't work for rating hazards. Since the concept of exponential scoring is foreign to most people, we have described logical breaks in the listed categories that coincide with the 3, 9, 27, and 81-point breaks in the scoring. Without these bench mark criteria we felt it would be very difficult to achieve uniform results from several raters.

Initially, the raters were covinced that using the specified set points was the only way to get uniform, reproducible results in scoring slope conditions. The general attitude of the raters was to want more precise definitions of the various criteria so they would know exactly where to categorize the site conditions. However, as they became more experienced with evaluating slopes, they saw the value and expressed a need for greater flexibility in scoring rather than being tied strictly to the score shown above the criteria for each category. We are convinced that some type of continuum of points scoring system is the best. As we progress into the next stage of work we will retain the exponential scoring system but will move toward using interpolation of points within that system.

REVISED RHRS

On the following pages is the new RHRS with accompanying narrative. The changes as previously discussed resulting from the shakedown test have been incorporated. It has been streamlined and is, we feel, more straightforward and accurate than the previous versions.

ROCKFALL HAZARD RATING SYSTEM (REVISED)

RATING	POINTS 3	POINTS 9	POINTS 27	POINTS 81
SLOPE HEIGHT	< 50 FT	50 TO 75 FT	75 TO 100 FT	> 100 FT
SLOPE CONTINUITY	Possible launch features	Some minor launch features	Many launching features	Major rock launching features
DITCH EFFECTIVENESS	Good catchment	Moderate catchment	Limited catchment	No catchment
AVERAGE OCCURRENCE OF VEHICLES IN ROCKFALL ZONE	< 25% of the time	25 - 50% of the time	50 - 75% of the time	> 75% of the time
AASHTO DECISION SITE DISTANCE	Adequate site distance, Within design range	Moderate site distance, 80-100% of low design value	Limited site distance 50-80% of low design value	Very limited site distance < 50% of low design value
ROADWAY WIDTH INCLUDING PAVED SHOULDERS	> 44 feet	44 - 30 feet	30 - 20 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
GEOLOGIC CHARACTER — CASE 1 — ROCK FRICTION	Rough, Irregular	Undulating	Planar	Clay infilling, or slickensided
GEOLOGIC CHARACTER — CASE 2 — STRUCTURAL CONDITION	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
GEOLOGIC CHARACTER — CASE 2 — DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference, favorable structure	Large difference, unfavorable structure
BLOCK SIZE / QUANTITY OF ROCKFALL/EVENT	< 12 IN / < 1 cubic yard	1 to 2 FT / 1 to 3 cubic yards	2 to 5 FT / 3 to 10 cubic yards	> 5 FT / > 10 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 3

The following list describes each category separately and sets forth our present guidance to raters:

SLOPE HEIGHT	< 50 FT	50 TO 75 FT	75 TO 100 FT	> 100 FT

1. **Slope Height** - This item represents the vertical height of the slope not the slope distance. Rocks on high slopes have more potential energy than rocks on lower slopes, thus they present a greater hazard and receive a higher rating. Measurement is to the highest point from which rockfall is expected. If rocks are coming from the natural slope above the cut, use the cut height plus the additional slope height (vertical distance). The slope height is estimated visually if cross-section or topo map is not readily available.

SLOPE CONTINUITY	Possible launch features	Some minor launch features	Many launching features	Major rock launching features

2. **Slope Continuity** - This item is an evaluation of the impact slope irregularities or "launching features" will have on falling rocks. It is rated because launching features can negate the benefit expected from a properly sized fallout area. First, evaluate whether any of the irregularities, natural or man-made, on a slope will launch falling rocks onto the paved portion of the roadway. Then, score the slope based on the density and size of these features. The following is a description of the individual rating categories:

3 points — <u>Possible Launch Features</u> Few, scattered features that may launch a rock or may develop into launch features. This category pertains to the features that are not clearly definable as launch features. If they will definitely launch rocks, they fall in the "some minor launch features" category.

9 points — <u>Some Minor Launch Features</u> Few, scattered launch features that could effect falling rocks. This includes slopes where the number and size of the features are small enough that most falling rocks probably won't strike them.

27 points — <u>Many Launching Features</u> This includes slopes where these features are numerous enough or significant enough that many of the rocks that fall are likely to be launched.

81 points — <u>Major Launching Features</u> Major features such as benches, ledges, or slope breaks that will launch all or nearly all rocks that fall. Benches filled in with slope ravel constitutes a major launching feature. Wide benches or shelves with favorable dips that will catch falling materials do not fall in this category. The "major" refers to the effects of the feature on the rockfall hazard not just the dimensions of the feature.

DITCH EFFECTIVENESS	Good catchment	Moderate catchment	Limited catchment	No catchment

3. **Ditch Effectiveness** - The effectiveness of a ditch is measured by its ability to prevent falling rock from reaching the roadway. In estimating the ditch effectiveness, the rater should consider several factors, including the slope height and angle; the ditch width, depth and shape; and the size of anticipated rockfall. Valuable information on ditch performance can be obtained from maintenance personnel. Rating points should be assigned as follows:

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 roadway.

AVERAGE OCCURRENCE OF VEHICLES IN ROCKFALL ZONE	< 25% of the time	25 - 50% of the time	50 - 75% of the time	> 75% of the time

4. **Average Occurrence of Vehicles in Rockfall Zone** - This category measures the percentage of time that a vehicle will be present in the rockfall hazard zone. The percentage is obtained by using a formula (shown below) based on slope length, average daily traffic (ADT), and the posted speed limit at the site. A rating of 100% means that on average a car can be expected to be within the hazard section 100% of the time. Care should be taken to measure only the length of a slope where rockfall is a problem. Over estimated lengths will strongly skew the formula results. 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 car is present within the measured section. The formula used is:

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

AASHTO DECISION SITE DISTANCE	Adequate site distance, Within design range	Moderate site distance, 80-100% of low design value	Limited site distance 50-80% of low design value	Very limited site distance < 50% of low design value

5. **AASHTO Decision Site Distance (DSD)** - Decision site distances are shown on Table III-3 taken from AASHTO's Policy on Geometric Design of Highways and Streets. When measuring DSD, the 3.5-ft eye height and 6-in object height criteria should be used. Measurement techniques are explained in detail in the AASHTO manual. The rater should remember that both horizontal and vertical site distances should be evaluated. Because actual design speeds are difficult to obtain for some sections of road, the posted speed limit should be substituted for the design speed.

Design Speed (mph)	Time(s): Premaneuver: Detection & Recognition	Time(s): Premaneuver: Decision & Response Initiation	Time(s): Maneuver (Lane Change)	Decision Sight Distance (ft): Summation	Decision Sight Distance (ft): Computed	Decision Sight Distance (ft): Rounded for Design
30	1.5-3.0	4.2-6.5	4.5	10.2-14.0	449- 616	450- 625
40	1.5-3.0	4.2-6.5	4.5	10.2-14.0	598- 821	600- 825
50	1.5-3.0	4.2-6.5	4.5	10.2-14.0	748-1,027	750-1,025
60	2.0-3.0	4.7-7.0	4.5	11.2-14.5	986-1,276	1,000-1,275
70	2.0-3.0	4.7-7.0	4.0	10.7-14.0	1,098-1,437	1,100-1,450

Table III-3. Decision sight distance. (Source: Ref. 10)

ROADWAY WIDTH INCLUDING PAVED SHOULDERS	> 44 feet	44 - 30 feet	30 - 20 feet	< 20 feet

6. **Roadway Width** - This dimension is measured perpendicular to the highway centerline from edge of pavement to edge of pavement. This measurement represents the available maneuvering room to avoid a rockfall.

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 structure

7./8. **Geologic Character** - The geologic conditions of the slope are evaluated with this category. Since the conditions that cause rockfall generally fit into 2 categories we have developed a Case 1 and Case 2 rating criteria. Case 1 is for slopes where joints, bedding planes, or other discontinuities, are the dominant structural feature of a rock slope. Case 2 is for slopes where differential erosion is the dominant structural condition. The rater should use whichever Case best fits the slope when doing the evaluation. If both situations are present, both are scored but only the worst case (highest score) is used in the rating. The following is a description of these categories:

<u>Case 1</u> — <u>Structural Condition</u> Adverse joint orientation, as it is used here, involves considering such things as rock friction angle, joint filling, and hydrostatic head if water is present. Some joints may dip out of a slope at low angles without being in the adverse orientation category. "Continuous" refers to joints greater than 10 feet in length.

3 points — <u>Discontinuous Joints, Favorable Orientation</u> Jointed rock with no adversely oriented joints, bedding planes, etc.

9 points — <u>Discontinuous Joints, Random Orientation</u> Rock slopes with randomly oriented joints creating a three-dimensional pattern. This type of pattern is likely to have some scattered blocks with adversely oriented joints but no dominant adverse joint pattern is present.

27 points — Discontinuous Joints, Adverse Orientation
Rock slope exhibits a prominent joint pattern, bedding plane, or other discontinuity, 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, bedding plane, or other discontinuity, with an adverse orientation and a length of greater than 10 feet.

Case 1 — Rock Friction This parameter directly effects 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 a surface. Macro roughness is the degree of undulation of the overall joint. Micro roughness is the texture of the surface of the rock. In areas where joints contain highly weathered rock or where movement has occurred causing slickensides or fault gouge to form, the rockfall potential is greater. In cases where joints have healed, for example by secondary mineralization, the rockfall potential may be lower. Since the categories listed below are measures of friction they are negated by open joints. If a slope is dominated by open joints, a worse case condition exists and a maximum score should be given.

3 points — Rough, Irregular The surface of the joints are rough and the joint planes are irregular enough to cause interlocking. This macro and micro roughness provides an optimal friction situation.

9 points — Undulating Also macro and micro rough but without the interlocking ability.

27 points — Planar Macro smooth and micro rough joint surfaces. Surface contains no interlocking or undulations. Friction is derived strictly from the roughness of the rock surface.

81 points — Clay Infilling, or Slickensides Low friction materials, such as clay and weathered rock, separate the rock surfaces negating any micro or macro roughness of the joint planes. These infilling materials have much

lower friction angles than a rock on rock contact. Slickensides, which is a micro and macro smooth polished surface, also has a very low friction angle and belongs in this category.

Case 2 — Structural Condition This case is used for slopes where differential erosion is the dominant structural feature. This may include: easily weathered rock units that undermine more durable units; highly variable units that weather causing resistant rocks to fall such as conglomerates, mudflows, etc.; rocky soil slopes that weather causing the rocks to fall.

3 points — Few Differential Erosion Features Minor localized differential erosion. Not distributed throughout the slope. This category is for slopes that fit the above description but don't have a serious or regular rockfall problem. If a localized area is causing a serious rockfall problem, the length of the slope being rated should be reduced and it should fall in the 27 or 81-point category.

9 points — Occasional Erosion Features Minor differential features that are widely distributed throughout the slope. This category is for slopes where the features are numerous and widely distributed but the rockfall quantity and frequency is low.

27 points — Many Erosion Features Differential erosion features are large enough or numerous enough to be the dominant structural feature of the slope. This category is for slopes that are a serious or consistent rockfall problem.

81 points — Major Erosion Features Severe cases such as erosion-created dangerous overhangs; oversteepened soil/rock slopes or talus slopes; or wherever extreme differences in erosion rates are producing continuous or serious rockfall problems.

Case 2 — Difference in Erosion Rates

3 points — Small Difference The difference in erosion rates is sufficient to create overhangs of a few inches or to rarely release small gravels or cobbles from a predominantly soil slope.

9 points — <u>Moderate Difference</u> The difference in erosion rates between materials on the slope is such that significant (less than 3 feet wide) overhangs may develop over several seasons, or many small gravels and cobbles or occasional boulders are released from a predominantly soil slope.

27 points — <u>Large Difference, Favorable Structure</u> The difference in erosion rates creates large overhangs (greater than 3 feet) in only a few seasons. However, the resistant material is massive or jointed such that several feet (several years) of overhang may build up before failure produces a rockfall. This includes easily eroded slopes that release abundant cobbles and small boulders.

81 points — <u>Large Difference, Unfavorable Structure</u> The difference in erosion rates is large but the the structure of the more resistant material is such that rockfall will be a continuous problem. This includes easily eroded slopes that release large boulders or pockets of boulders.

BLOCK SIZE / QUANTITY OF ROCKFALL/EVENT	< 12 IN / < 1 cubic yard	1 to 2 FT / 1 to 3 cubic yards	2 to 5 FT / 3 to 10 cubic yards	> 5 FT / > 10 cubic yards

9. **Block Size or Quantity of Rockfall Per Event** - This measurement should be representative of whichever type of rockfall event is most likely to occur. 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 quantity per event should be used. This 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.

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

10. **Climate and Presence of Water on Slope** - Water and freeze/thaw cycles both contribute to the weathering and

movement of rock materials. 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 interpreted from knowledge of the freezing conditions and its effects at the site.

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

ROCKFALL HISTORY	Few falls	Occasional falls	Many falls	Constant falls

11. **Rockfall History** - This information is best obtained from the maintenance person responsible for the slope in question. It directly represents the known rockfall activity at the site. There may be no history available at newly constructed sites or where poor documentation practices have been followed and a turnover of personnel has occurred. In these cases, the maintenance cost at a particular site may be the only information that reflects the rockfall activity at that 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 should be performed. As a better database of rockfall occurrences is developed, more accurate conclusions for the rockfall potential can be made.

3 points — <u>Few Falls</u> - Rockfalls have occurred several times according to historical information but it is not a persistent problem. If rockfall only occurs a few times a year or less, or only during severe storms this category should be used. This category is also used if no rockfall history data is available.

9 points — <u>Occasional Falls</u> - Rockfall occurs regularly. Rockfall can be expected several times per year and during most storms.

27 points — <u>Many Falls</u> - 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 is 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.

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In addition to scoring the above categories, the rating team should gather enough field information to recommend which rockfall remedial measure is best suited to the rockfall problem. With management's involvement, the geologist should determine whether to recommend a total fix or to take a hazard reduction approach. In either case, a preliminary cost estimate should be prepared.

CONCLUSIONS

This latest study has allowed ODOT's staff to gain valuable field experience in rating slopes and to make significant improvements to the RHRS. We are confident of the system's value as a tool in prioritizing rock slopes for remedial work. However, there remains additional work to complete the total package. This work consists of:

1. Developing an in-state database system to facilitate data reduction and storage.
2. Deriving a method to integrate the RHRS with the benefit/cost ratio for final project development prioritization.
3. Continuing the refinement of the RHRS through additional field use and full scale implementation.

Once completed, the RHRS will allow States to systematically evaluate the rockfall hazards along their highways. This will permit them to prudently direct project funding at their most potentially dangerous sites. A significant added benefit is reduced liability from rockfall caused injury/accident lawsuits.

We wish to extend our appreciation to the Federal Highway Administration for providing funding for this phase of the RHRS development.

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APPENDIX A

STATEWIDE ROCKFALL LOCATIONS

There are factors other than just accident listings which must be taken into consideration when prioritizing hazardous rockfall locations. These include the annual maintenance costs, the amount and sizes of rock that fall and their potential for landing within the driving lanes and the average daily traffic of the highways.

Each Region Engineer prioritizes the rockfall locations within his Region because of his familirity with each location and the factors mentioned above and submits the lists to the Traffic Engineering Section. The Traffic Section further investigates these locations using accident listings and annual maintenance costs.

The benefit/cost ratio shown, which uses the current accident cost figures from the National Safety Council, was used for the original statewide prioritization of the rockfall locations and will continue being used until completion of the RHRS survey of the highway system.

$$B/C = \frac{1{,}200(P) + 9{,}200(I) + 240{,}000(F) + \text{Maint Cost} \times PWF}{(\text{No. of Years}) \quad (\text{Cost of Project})}$$

P = Property Damage Only
I = Number of Injuries
F = Number of Fatalities
PWF = Present Worth Factor (20 yrs. @ 10%)

When using this equation any accident involving property damage only is counted as one "P" regardless of how many cars were involved. However, when injuries and/or fatalities are involved property damage is excluded and the total number of injuries and/or fatalities are counted.

This equation gives a good balance between the worth of an injury, fatality and property damage only, based on todays costs. It also takes into account the annual reduction in maintenance costs, the number of years used in the study and the project cost so that projects of varying magnitude can be compared. These costs will be updated periodically so that they may be compared to future listings.

ROCKFALL LOCATIONS

B/C RATIO PROJECT PRIORITY LIST

(4/88)

RANK	HIGHWAY NUMBER AND NAME		MILEPOST SECTION	PROJECT DESCRIPTION	COST X $ 1000
1	5	John Day	103.80 - 104.20	Bench	$ 175
2	4	The Dalles - California	268.90 - 269.50	Cut/Fallout	489
3	2	Columbia River	23.00 - 62.00	BM Barrier	1,660
4	415	Dooley Mountain	24.00 - 24.00	Fallout Area	150
5	35	Coos Bay - Roseburg	8.30 - 8.70	Realign Barrier	172
6	3	Oswego	3.64 - 8.04	GM Barrier	150
7	12	Baker - Copperfield	33.00 - 34.25	Bench	130
8	215	Clear Lake-Belnap Springs	6.02 - 6.06	Scale/Screen	60
9	11	Enterprise - Lewiston	0.00 - 5.00	Bench/Fallout	250
10	6	Old Oregon Trail	318.00 - 318.00	Rockfence	40
11	12	Baker - Copperfield	36.60 - 27.90	Bench/Fallout	65
12	4	The Dalles - California	271.80 - 272.00	Slope	42
13	2	Columbia River	197.62 - 203.22	GM Barrier	1,250
14	10	Wallowa Lake	40.75 - 40.83	Rock Fence	35
15	351	Joseph - Wallowa	2.00 - 5.45	Rock Fence	55
16	28	Pendleton - John Day	52.30 - 52.42	Fence	38
17	4	The Dalles - California	259.30 - 259.30	Fallout/Barrier	70
18	37	Wilson River	31.00 - 32.20	Screen/Tunnel Cut	722
19	10	Wallowa Lake	34.09 - 35.00	Bench/Fallout	150
20	2	Columbia River	81.00 - 81.00	Bin Wall	108
21	270	Lake of the Woods	31.63 - 31.77	Slope	120
22	5	John Day	174.90 - 174.90	Rockfall Correction	15
23	221	Hood River	11.10 - 11.80	Slope/Fallout	770
24	10	Wallowa Lake	38.20 - 38.80	Bench	85
25	10	Wallowa Lake	41.80 - 42.00	Bench	45
26	20	Klamath Falls - Lakeview	44.60 - 44.80	Cut/Fallout	54
27	12	Baker - Copperfield	67.90 - 68.05	Fallout Area	55
28	15	McKenzie	10.00 - 10.10	Slide	594
29	350	Little Sheep Creek	22.64 - 24.77	Bench/Fallout	130
30	171	Clackamas	31.90 - 44.50	Bench/Fallout	18,480
31	350	Little Sheep Creek	27.90 - 28.12	Bench	45
32	350	Little Sheep Creek	25.42 - 26.79	Bench/Fallout	75
33	6	Old Oregon Trail	355.40 - 355.40	Rockfall Correction	25
34	6	Old Oregon Trail	355.60 - 355.60	Rockfall Correction	25
35	10	Wallowa Lake	60.00 - 60.10	Bench	50
36	10	Wallowa Lake	62.17 - 62.85	Bench	95
37	48	John Day - Burns	2.20 - 5.70	Rockfall Correction	40
38	163	Silver Falls	37.96 - 37.96	Scale/Screen	100
39	26	Mt Hood	72.68 - 73.40	Bench Cut	1,956
40	48	John Day - Burns	62.90 - 62.90	Rockfall Correction	45
41	48	John Day - Burns	64.10 - 64.10	Rockfall Correction	25
42	48	John Day - Burns	61.80 - 62.20	Rockfall Correction	30
43	233	West Diamond Lake	.30 - .40	Fallout Area	150
44	455	Olds Ferry - Ontario	2.70 - 2.70	Rockfall Correction	15
45	341	Ukiah - Hilgard	34.50 - 34.80	Bench	80
46	22	Crater Lake	37.18 - 37.69	Bench Cut	390
47	215	Clear Lake - Belnap Springs	9.60 - 9.70	Screening	410
48	71	Whitney	42.00 - 42.00	Bench/Fallout	90
49	12	Baker - Copperfield	6.00 - 6.00	Bench/Fallout	75
50	41	Ochoco	93.00 - 97.00	Fallout Area	500

51	12	Baker - Copperfield	24.65 - 24.75	Bench	50
52	455	Olds Ferry - Ontario	1.30 - 1.60	Rockfall Correction	50
53	11	Enterprise - Lewiston	35.90 - 36.16	Bench/Cut Slope	65
54	2W	Lower Columbia	8.55 - 11.00	Rock Screen	560
55	9	Oregon Coast	131.70 - 131.90	Scale/Screen	500
56	6	Old Oregon Trail	227.24 - 228.25	Cut Slopes/Fence	820
57	8	Oregon - Washington	21.88 - 22.43	Rockfall Area	454
58	18	Willamette	19.50 - 24.60	Cut/Fallout	3,000
59	35	Coos Bay - Roseburg	48.80 - 49.20	Beach Fallout	490
60	270	Lake of the Woods	22.96 - 27.65	Slope/Fallout	854
61	5	John Day	172.10 - 172.10	Rockfall Correction	40
62	41	Ochoco	50.00 - 57.00	Fallout Area	800
63	48	John Day - Burns	61.30 - 61.30	Rockfall Correction	20
64	233	West Diamond Lake	4.48 - 5.90	Fallout Area	1,000
65	11	Enterprise - Lewiston	40.42 - 40.42	Bench/Cut Slope	50
66	455	Olds Ferry - Ontario	2.10 - 2.10	Rockfall Correction	25
67	350	Little Sheep Creek	12.40 - 14.55	Bench/Fallout	110
68	350	Little Sheep Creek	18.00 - 18.07	Bench/Fallout	60
69	449	Huntington	1.50 - 1.50	Rockfall Correction	40
70	1	Pacific	147.46 - 197.69	Scale/Fallout	500
71	1E	Pacific East	12.62 - 17.76	Rock Bench/Screen	2,240
72	6	Old Oregon Trail	259.35 - 259.35	Recut/Bench	150
73	4	The Dalles - California	261.50 - 262.30	Slope/Fallout	357
74	26	Mt Hood	100.30 - 102.20	Fallout Area	1,649
75	162	North Santiam	43.35 - 44.40	Scale/Screen	750
76	35	Coos Bay - Roseburg	47.60 - 47.70	Drainage/Pave	1,037
77	48	John Day - Burns	11.20 - 12.00	Rockfall Correction	150
78	48	John Day - Burns	59.00 - 59.00	Rockfall Correction	30
79	350	Little Sheep Creek	7.00 - 8.00	Bench/Fallout	125
80	1	Pacific	116.38 - 116.48	Rockfall/Slide Repair	490
81	2	Columbia River	90.40 - 113.50	Fallout Area	1,106
82	26	Mt Hood	49.12 - 51.58	Bench/Fallout	5,000
83	6	Old Oregon Trail	270.00 - 270.00	Bench/Fallout	150
84	9	Oregon Coast	40.50 - 41.10	Screening	1,500
85	162	North Santiam	39.80 - 40.00	Scale/Screen	1,500
86	22	Crater Lake	36.65 - 36.95	Bench	224
87	10	Wallowa Lake	30.14 - 33.00	Bench/Fallout	1,000
88	173	Timberline	0.80 - 2.80	Screen/Fallout	840
89	233	West Diamond Lake	5.30 - 5.70	Bench	200
90	330	Weston - Elgin	17.60 - 17.91	Bench/Fallout	60
91	66	LaGrande - Baker	19.00 - 20.50	Bench/Fallout	100
92	2	Lower Columbia	104.90F- 106.00F	Fallout/Area	815
93	341	Ukiah - Hilgard	10.18 - 10.28	Fallout/Area	370
94	1	Pacific	109.40 - 109.50	Slide/Repair	994
95	2	Columbia River	52.10 - 52.60	Extend Wall	1,540
96	2	Columbia River	74.50 - 75.40	Relocate Highway	2,800
97	2W	Lower Columbia	62.30 - 63.70	Scale/Screen	1,180
98	2W	Lower Columbia	43.80 - 44.25	Scale/Barrier	840
99	125	Crown Point	4.10 - 4.50	Bench/Fallout	3,130
100	125	Crown Point	10.80 - 15.10	Bench/Fallout	3,150
101	330	Weston - Elgin	38.55 - 39.28	Cut Bank/Fallout	75
102	330	Weston - Elgin	37.23 - 37.81	Bench/Fallout	90
103	330	Weston - Elgin	32.70 - 32.80	Bench	80
104	330	Weston - Elgin	29.94 - 30.87	Bench/Fallout	90
105	330	Weston - Elgin	27.85 - 28.40	Bench/Fallout	60

APPENDIX B

REPORT ON ODOT'S
ROCKSLOPE DESIGN POLICY

APPENDIX B

OREGON'S ROCK SLOPE DESIGN PRACTICE

INTRODUCTION

The State of Oregon adopted the following Rock Cut Slope Policy in February, 1986. Prior to that time standard cuts in rock were made on a 0.25:1 slope with a bench every 30 feet. We felt this template approach to rock slope design in no way addressed all the possible slope conditions, nor did we see any consistent benefit from benching the slopes.

The purpose of the policy is to establish new slope design standards for rock cuts and to actively involve the Region Geology Groups and the headquarters Geotechnical Group in the rock slope design process. This involvement should insure that the rock cuts are safe to construct and will optimize long-term safety for the public. In general, the policy includes four sections that deal with rock slopes. These sections cover the cut slope inclination, rock fallout area requirements, the use of benches, and rock slope stabilization techniques.

CUT SLOPE INCLINATION

The cut slope inclination is controlled by the structural geology and the stability of the rock units. Slope recommendations addressing these features are included in the geology report. The slope recommendation may be based on precedence, subsurface exploration and/or statistical mapping and analysis. The level of investigation is controlled by the scope of the project and the level of confidence required as determined by the Region Geologist and the Geotechnical Engineer. The recommendation should include the steepest continuous slope (without benches) that satisfies physical and stability considerations. Rock unit slopes of vertical, 0.1:1, 0.25:1, 0.5:1, 0.75:1 and 1:1 are commonly considered.

ROCK FALLOUT AREAS

The policy directs designers to include rock fallout areas between the toe of the slope and the travel lane where hazardous rockfall could occur. The minimum dimensions of the fallout areas are controlled by the cut slope inclination and height. This criteria was developed by A. M. Ritchie for the State of Washington and was included in chart form in the FHWA's "Rock Slopes" manual, 1981. We have found the use of fallout areas along with controlled blasting techniques used to develop the cut slope to be the most effective and satisfactory means for controlling rockfall and reducing rockfall hazard.

INTERMEDIATE SLOPE BENCHES

The use of intermediate slope benches is limited to the unique site conditions covered in Section C of the policy. We researched the origin of the previous benching requirement. The people we interviewed felt the need for benches was tied to a safety regulatory requirement; however, none was found. The field evidence we gathered indicated that no consistent benefit was gained by benching slopes. In fact, we observed that in some instances poorly maintained benches actually created a hazardous situation. As rockfall debris accumulated on the benches, their ability to retain rockfall decreased. Eventually, the filled benches imparted a horizontal direction to the falling rocks propelling them toward the highway. The reasons for low maintenance were numerous, including: no access to the bench was originally provided, portions of benches became isolated beyond a failed section, filled in benches are not always visible from the road or simply because a low-priority was established for this task by our very busy maintenance personnel. By eliminating slope benches in most instances and dealing with rockfall by creating fallout areas at the highway level, the cut construction and future maintenance is simplified and the long-term safety is enhanced.

ROCK SLOPE STABILIZATION TECHNIQUES

Section D of the policy outlines some of the more common rock slope stabilization techniques. It also requires the Geotechnical Group to review proposed techniques and to supply the appropriate design details. This centralized effort promotes uniformity across the state.

CONCLUSION

This policy shown on the following pages has been well received by both our field and headquarters personnel. It has reduced confusion and has greatly improved our level of confidence with the design process. In addition, having a written policy that is consistent with current standards of practice and is utilized state-wide provides us with a sound starting point when faced with litigation.

Sec. 807.03 Cut Slopes

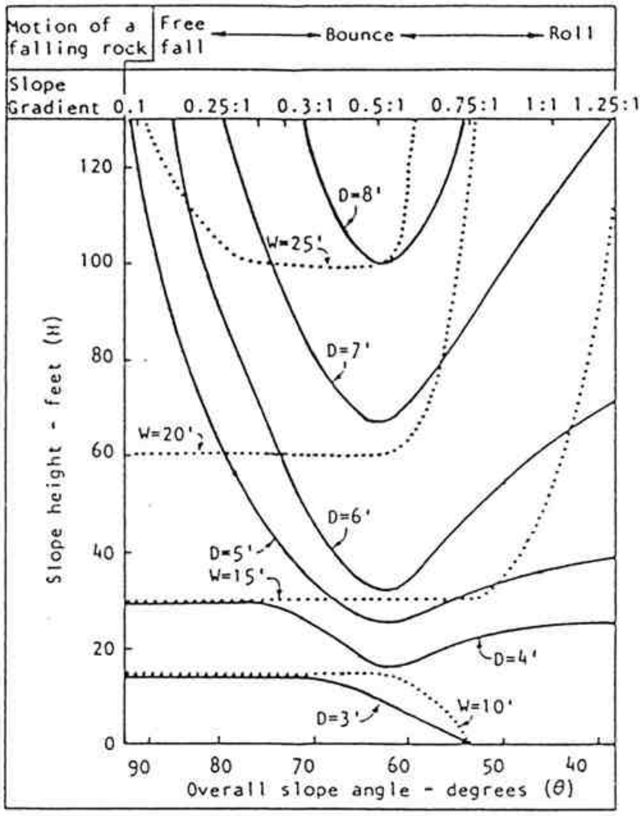
A. Rock Cut Slopes - The purpose of rock slope design is to develop rock cuts that will be safe to construct and will provide long term safety for the public. The inclination of rock cut slopes should be based on the structural geology and stability of the rock units, as described in the Geology Report. Rock unit slopes of vertical, 0.25:1, 0.5:1, 0.75:1 and 1:1 are commonly considered. The designed rock cut slope should be the steepest continuous slope (without benches) that satisfies physical and stability considerations. Controlled blasting (using presplitting and trim blasting techniques) is normally required for rock cut slopes from vertical to 0.75:1. The purpose of controlled blasting is to minimize blast damage to the rock backslope to help insure long-term stability, improve safety, and lessen maintenance.

B. Rock Fallout Areas - Fallout areas should be used where hazardous rockfall could occur. A fallout area is a nontraveled area between the highway and the cut slope with minimum width and depth requirements. The minimum dimensions should be determined based on rock cut slope inclination and height, as shown in Figure 807-2. The depth of the fallout area varies with the slope configuration. This depth may be achieved in a number of ways including excavation and/or by placing suitable retaining structures at the highway shoulder. Where the slopes are inclined at a 0.75:1 slope or flatter, and where the anticipated size of a single falling rock is less than 2 feet in diameter, catch fences may be considered as a substitute for depth of fallout.

C. Benches - Soil and rock slopes may need a modification with benches to conform to the environment or for safety and economic concerns. Following are some appropriate bench applications:

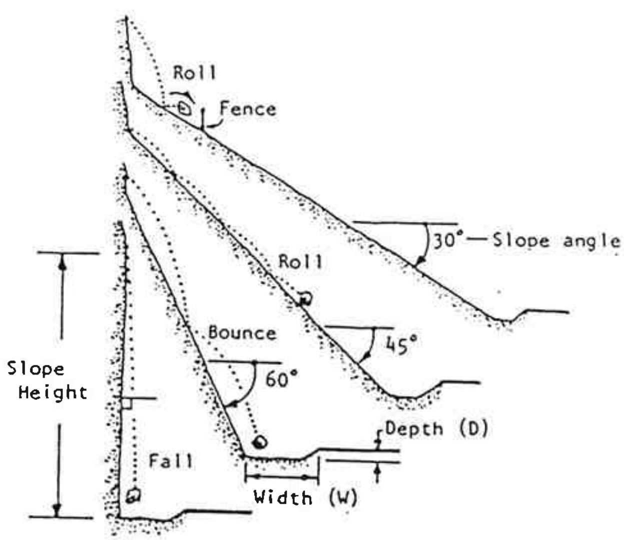
1. Benching may improve slope stability where continuous slopes are not stable.
2. Where maintenance due to sloughing of the overburden soil slope may be anticipated a bench will provide access and working room at the overburden rock contact.
3. Developing an access bench may facilitate construction where the top of cut begins at an intermediate slope location.
4. On very high cuts, benches may be included where rockfalls during construction are anticipated.
5. Where necessary, benches may be located to intercept groundwater moving to a known elevation.

The need for benches will be evaluated in the geology and geotechnical investigations and described in the resulting



FOOTNOTE:

Ditch depths shown on this chart are based on Ritchie's Original Criteria (1963). In actual practice ODOT typically uses ditch depths of 4 feet or less. Ditches deeper than 4 feet are only used in rare circumstances.



(Figures taken from FHWA Manual "Rock Slopes" - Nov. 1981 USDOT Chapter 12 Page 19)

Figure 807-2