SPECIAL PUBLICATION 37

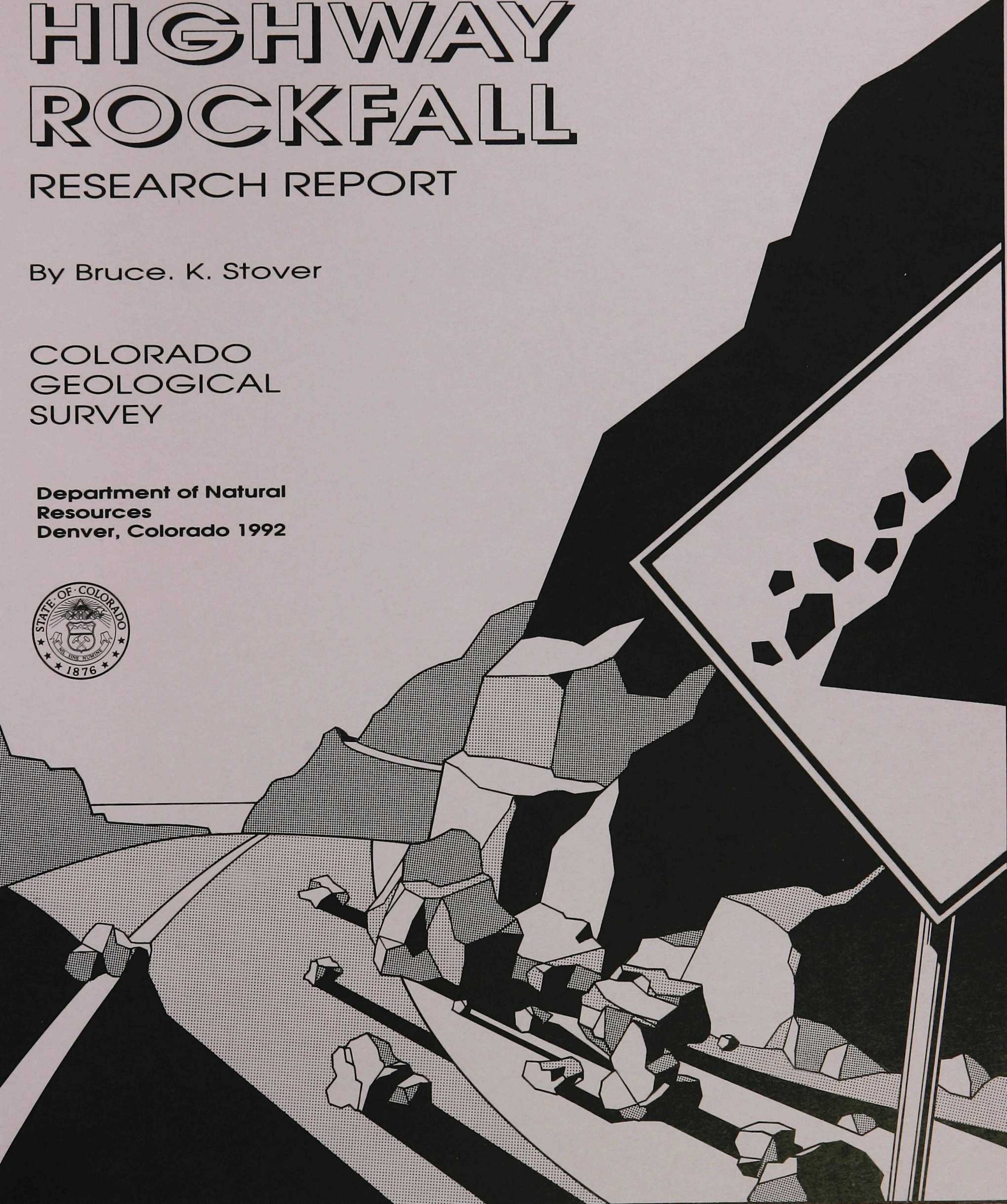
HIGHWAY ROCKFALL

RESEARCH REPORT

By Bruce. K. Stover

COLORADO
GEOLOGICAL
SURVEY

**Department of Natural
Resources
Denver, Colorado 1992**



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Colorado Geological Survey
Department of Natural Resrouces
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PURPOSE AND APPROACH

This research project is directed at developing and demonstrating a system for cost effectively evaluating and prioritizing highway rockfall hazards state wide. The project has been designed to produce a method for evaluating very large segments of the highway system without getting bogged down with extensive areas of minor maintenance problems, or areas of possible but very rare rockfall events.

The proposed approach and prototype system is based on the premise that life-threatening highway rockfall accidents most often occur in the places where they have occurred in the past. Concentrating on those areas which have a history of rockfall accidents initially screens out the hundreds of minor or nuisance rockfall sites which generally do not cause accidents. This focuses mitigation efforts on those areas which, through a combination of geology, climate, traffic volume, and physical aspects of the highway, have the highest incidences of rockfall accidents.

The prototype system consists of three parts: 1) A computer sorted set of data bases, including past highway rockfall accidents since 1976; 2) A ride through program with maintenance patrol personnel, and 3) A system for categorizing and ranking individual highway rockfall hazard sites.

METHOD OF STUDY

Several existing data bases were assembled and used to create the prototype Colorado Rockfall Accidents on State Highways (CRASH) computer program. This program uses highway mileage data from the Colorado Roadway Information System (CORIS) combined with the Colorado Department of Highways (CDOH) accident data base. A count of the number of accidents due to rockfall at each mile segment of a given highway is generated and used to identify and rank rockfall-prone parts of highways in the state. This information can be presented in a variety of forms.

As a pilot study, we necessarily pre-selected five known highway rockfall areas to develop the Rockfall Hazard Ranking system. These were chosen to provide different geologic, geographic, and physical settings on which to test the ranking and categorizing scheme. These areas were:

1. Highway 6 in Clear Creek Canyon
2. US 40 over Berthoud Pass
3. Highway 82 from Aspen to Basalt
4. I-25 over Raton Pass
5. I-70 from Silverplume to Georgetown

These areas were run through the prototype CRASH program to identify the mileposts or points within each where the most rockfall accidents had occurred. In order to assess the accuracy of the accident data base, as well as identify those areas where recent improvements or maintenance efforts were having an effect on rockfall accident frequency, a "ride-through" with maintenance patrols was conducted through each of the three pre-selected areas in Engineering District One. A geologist noted and ranked those areas which were pointed out as having maintenance problems and cleanup costs associated with rockfalls. These locations were then compared with locations derived from the accident data base system to set priority areas, and make sure no seriously hazardous sites were missed.

Geologists then visited the sites identified in this manner and ranked and categorized each segment using the prototype site ranking system. Data on the geology, slopes, drainage, and other physical aspects contributing to rockfall were collected. Segments were delineated based on geologic and slope factors, and each segment received a numerical ranking.

RESULTS OF STUDY

This pilot study produced a prototype computer based highway rockfall hazard ranking system, (CRASH), which can be used to identify those areas of the states highway system which have the highest incidences of rockfall accidents, as well as any area which has had a reported rockfall accident since 1976. Rockfall accident history and rockfall hazard areas can be identified for every highway in the State in a variety of report formats.

The existing Oregon rockfall hazard ranking system (ODOT system) was selected and studied to determine if it addressed the varied geologic as well as physical rockfall situations in Colorado. This system was adapted and slight modifications made in order to suit the requirements of our prototype hazard ranking scheme. Our recommendation is to adopt the final ODOT hazard ranking system for use in Colorado, using slightly modified scoring forms developed in this study.

Implementation of the Highway Rockfall Hazard Evaluation system was demonstrated on five pre-selected areas. After being guided by the CRASH program to the point or milepost in each area with the most reported rockfall accidents, each mile or point was ranked using the ODOT system. The areas were broken down into a series of segments which were identified as having similar geologic and physical rocfall attributes for ranking and mitigation purposes. Each segment was scored by a geologist using the criteria of the ODOT system in order to determine the most severe rockfall hazard sites. Individual scored segments were plotted on topographic maps. The field data collected in this manner can be used to determine which remedial measures are best suited to a particular site, help in preparing preliminary cost estimates, and provide initial geologic information for design of remedial approaches.

RECOMMENDATIONS

Our study demonstrates that data developed and collected by this three-part approach can be used to direct the Highway Department to those sites which have the highest rockfall hazard. These sites should be first to receive corrective action in order to achieve the greatest reduction in accidents. It is expected that as funds become available for hazard mitigation, work will proceed down a prioritized list so that the most hazardous sites in each district are addressed first. The Oregon Department to Highways (ODOT) Rockfall Hazard Rating System (RHRS) should be adopted by the CDOH for use with the phased approach developed during this pilot study.

As mitigation work proceeds, the CRASH program developed in this pilot study should be used to track the effectiveness of mitigation solutions, as well as continually update and identify the current highest priority sites Statewide. This can be accomplished simply by posting all newly reported rockfall accidents to the system, as well as any major rockfall cleanup operations which maintenance reports. A coordinated effect should be made between maintenance and the Highway Patrol/Safety Division to ensure accurate categorization and posting of all Highway Rockfall incidents and accidents. This will directly improve the accuracy of the CRASH ranking system.

PHASE 1: IDENTIFICATION OF ROCKFALL PRONE AREAS

PURPOSE AND APPROACH

The purpose of this phase of the study is to identify and rank, by milepost, those segments of state highways that have chronic problems with rockfall. Road segments with rockfall problems are identified either by the occurrence of vehicle accident(s) caused by rockfall, or identification by highway maintenance personnel as rockfall-prone areas (which do not necessarily result in accidents). A simple computer program, Colorado Rockfall Accidents on State Highways (CRASH) was developed to combine highway mileage data from the Colorado Roadway Information System (CORIS) with the Colorado Department of Highways (CDOH) accident database, and produce a count of the number of accidents due to rockfall at each milepost of a given highway. The data compiled by the program, when combined with information from highway maintenance personnel, can be used to identify and rank the rockfall-prone areas in the state. This information can be presented in a variety of forms.

The ranking generated in this phase of the study serves to direct the locations of the more detailed evaluations based on geologic conditions in Phase II, and narrows down the number of highway miles that will be included in Phase II.

DATA SOURCES

A number of data sources were explored and used in this phase of the study. Descriptions of the data sources are given below and, when applicable, the limitations of the data are discussed.

CORIS

CORIS is an extensive database used by CDOH which consists of information on everything from the width of the shoulder to the average daily traffic along all state highways in Colorado. A separate CORIS file exists for each year to accommodate changes in road conditions.

In this phase of the study, we extracted the mileage information and maintenance section and county identification from the 1987 CORIS file. We were thus working with highway mileages that existed in 1987.

CDOH Accident Database

In the state of Colorado, a form identified as the Investigator's Traffic Accident Report (ITAR) is filled out following a vehicle accident investigated by the Highway Patrol. This form includes information about the accident including such factors as the location, cause and resulting damage. The information from the form has been coded into the CDOH accident database since 1976.

In this phase of the study, we extracted information on the location of vehicle accidents whose primary cause was identified as "Rocks in Roadway". This search included the years 1976 through 1989, and gave us a good identifier of those road segments prone to rockfall-caused accidents during those years.

However, a number of short-comings exist with this data. From 1976 to 1980 the ITAR included the category of accients due to a "Large Boulder, (not in roadway)". An examination of accident reports showed that this category was used for accidents that appeared to be caused by rockfall, but was also frequently used for accidents caused by other factors which resulting in the vehicle impacting a large rock. From 1981 to 1989 the category was changed to "Large Boulder" and did not specify on or off road. Due to these ambiguities, we did not search on the "Large Boulder" category. In eliminating this category, we missed identifying some accidents that were actually caused by rockfall, but also avoided using a large number of accidents that were not.

Difficulties arose with the accident database even with the restrictive "Rocks in Roadway" search. Specifically, accidents caused by skidding on gravel were included in this category, as were accidents caused by debris falling from trucks into the roadway. However, a review of the reports for 80 randomly selected accidents attributed to rocks in the roadway revealed only 2.5 percent of the accidents to be non-rockfall related.

Although the accident database served to identify some areas prone to rockfall-related accidents, it by no means identified all areas. For example, accidents that do not result in serious injuries or substantial damage in rural areas are often not reported to the Highway Patrol due to the long response time.

Even though the accidents summarized in the accident reports are located to the nearest tenth of a mile, CDOH personnel informed us that the locations are not as accurate as they appear. We thus chose to work with integer mileposts in this phase of the study. Table 1 shows an example of this data.

In addition, note that we are matching highway mileages identified in the 1987 version of CORIS with those mileages identified in the accident database (those that existed in 1976 through 1987). Discrepancies are bound to arise in this match due to changing road conditions over these years.

Ride-Through Program with maintenance Personnel

Drive throughs with highway maintenance personnel familiar with the roadway were performed to identify sections of the road prone to rockfall, but that did not necessarily produce accidents. The drive through also serves to identify locations where the rockfall hazard has been mitigated. The drive through consisted of the interviewee assigning a ranking for the frequency of occurrence of rockfall for each segment of road based on the scale shown in Table 2, the mileage (to the nearest tenth of a mile), ranking, and additional comments were recorded by the interviewer. Table 3 is an example of a drive through along Interstate 70 from Idaho Springs to Copper Mountain. For this phase of the study, the information from the drive throughs was reduced to integer miles by using highest ranking (worst-case) in a given mile.

One apparent draw-back to this approach is the interviewees reluctance to assign the problems to a single class, preferring instead to assign a ranking which includes two classes.

For example, a segment that had loose rocks for several years and then stabilized for the latest few years would not necessarily fall into a single category. This segment would be rated "2" or "1" based only on the local parity of neighboring segments. That is, if the two segments on either side were "2" ratings, then the middle segment would be distinguished by a "1" rating to reflect it's stabilization.

Another problem was the normative approach each maintenance foreman used to determine segment rankings. This was apparent to the interviewer who rode with all the CDOH personnel. Often a ranking would be assigned that the interviewer would rank differently. These values were reviewed by both parties later and assigned to one value based on the inteviewers interpretation relative to other drive-throughs. It should be noted that the final rankings include only one value per segment.

Other Sources Investigated

The CDOH maintenance cost database was investigated as a potential source of data for rockfall clean-up expenditures which would serve to both identify and quantify the impact of non-accident producing but rockfall-prone areas. The maintenance cost database consists of a number of maintenance activities for which a cost has been assessed. Ideally, the time spent performing each of the various activities is recorded and thus the expenditure for each activity can be determined. The database includes an activity termed "Rock Run" which consists of cleaning rocks off the highway. However, CDOH personnel felt that the input into the database was not sufficiently consistent to be reliable and thus this source of data was not utilized.

Table 1. Highway mileposts with accidents due to rockfall sorted by number of accidents.

HIGHWAY SECT	MAINTENANCE SECT	MILE POST	NUMBER OF ACCIDENTS	COMMENTS
70	5	213	27	Straight Creek
70	2	124	26	Glenwood Canyon
70	5	226	25	Georgetown Incline*
70	2	125	23	Glenwood Canyon
70	5	211	22	Straight Creek
40	5	237	20	Berthoud Pass*
40	5	238	18	Berthoud Pass*
70	5	227	17	Georgetown Incline*
70	2	122	16	Glenwood Canyon
70	2	172	15	Vail
70	5	212	14	Straight Creek
160	7	161	14	Wolf Creek Pass
70	2	123	13	Glenwood Canyon
70	2	127	13	Glenwood Canyon
70	2	126	13	Glenwood Canyon
70	2	171	12	Vail
160	3	116	12	
70	9	215	11	
82	2	21	11	Aspen, Basalt*
160	7	174	10	
70	2	121	10	
6	5	267	9	Clear Creek Canyon*
82	2	12	9	Aspen, Basalt*
70	5	242	9	
40	5	239	9	Berthoud Pass*
70	5	178	9	
6	5	264	9	Clear Creek Canyon*
6	5	265	8	Clear Creek Canyon*
6	5	266	8	Clear Creek Canyon*
82	2	5	8	Glenwood Canyon
25	4	5	7	Raton Pass*
70	5	229	7	
70	2	110	7	
149	7	12	6	
160	7	160	6	
6	5	219	6	
70	5	240	6	
160	3	86	6	
70	2	118	6	
70	5	230	6	
6	5	268	6	
70	5	236	6	
25	4	4	6	Raton Pass*
70	5	244	6	
70	5	235	6	
70	2	57	5	
160	7	162	5	
70	5	216	5	
25	4	7	5	Raton Pass*
550	3	89	5	
6	5	269	5	

*Pilot Study Area

CRASH PROGRAM

CRASH is a simple dBase program designed to match the integer mileposts in CORIS with the CDOH accident database and to provide a count of the number of vehicle accidents due to rockfall at each milepost of a given highway.

In the current version, CRASH is interactive and requires only that the operator enter the highway to be analyzed. Future versions could include the option of analyzing by highway, maintenance section, or county.

Table 2. Ranking used during drive throughs with CDOH maintenance personnel (from Oregon Department of Transportation).

RANK	DESCRIPTION
0	**No Falls**—no rockfall maintenance activity
1	**Few Falls**—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.
2	**Occasional Falls**—Rockfall occurs regularly. Rockfall can be expected several times per year and during most storms.
3	**Many Falls**—Typically rockfall occurs frequently during a certain season, such as the winter or spring wet period, or the winter freeze-thaw, etc. This category is for sites where frequent rockfalls occur during a certain season and is not a significant problem during the rest of the year. This category may also be used where severe rockfall events have occurred.
4	**Constant Falls**—Rockfalls occur frequently throughout the year. This category is also for sites where severe rockfall events are common.

Primary Output

The primary output of the program consists of the highway, the milepost, the maintenance section in which the milepost falls, and the number of accidents within that mile. An example of the output is displayed graphically in Figure 1 as a plot of the number of accidents due to rockfall along Interstate 70 in Colorado for the years 1976 through 1989.

Secondary Output

The primary output from the program can be presented in a variety of forms. For example, Table 1 is a listing of the mileposts of Colorado Highways with the highest number of accidents due to rockfall for the years 1976 through 1989. This data can also be arranged by maintenance section or by highway.

DISCUSSION

For the most useful product, the output from CRASH can be combined with the results of interviews with highway maintenance personnel to identify the areas most prone to rockfall. Such a combination is shown, as an example, in Figure 2.

The road segments identified as having both a high number of accidents due to rockfall and a high rockfall occurrence rating by CDOH maintenance personnel should become the primary targets for Phase II assessment and future remediation. For example, data shown in Figure 2 indicates that the road segment between mileposts 209 and 214, immediately west of the Eisenhower Tunnel, is one of the highest priority candidates for Phase II evaluation. The road segment between mileposts 225 and 23, between Silver Plume and Georgetown, is also a high priority candidate.

Table 3. Rockfall hazard maintenance drive through from Copper Mountain to Idaho Springs.

Highway: Interstate 70
Information source: J. Gunn
Interviewed by: C. Carroll

BEGINNING MILEPOST	END MILEPOST	BEGINNING MILES	END MILES	RATING	REMARKS
193.3		67.5			Copper Mountain
196.1	193.3	64.7	67.5	0	Wide shoulder
196.5	196.1	64.3	64.7	1	Large benched outcrop
196.6	196.5	64.2	64.3	0	
196.9	196.6	63.9	64.2	1	Benched outcrop
198.4	196.9	62.4	63.9	0	
199.0	198.4	61.8	62.4	1	Large bedrock outcrop
199.5	199.0	61.3	61.8	0	
199.6	199.5	61.2	61.3	1	
199.8	199.6	61.0	61.2	1	Bedrock outcrop
205.0	199.8	55.8	61.0	0	Lake Dillon
205.6	205.0	55.2	55.8	0	Silverthorne
205.9	205.6	54.9	55.2	1	
206.1	205.9	54.7	54.9	3	Rockface
206.6	206.1	54.2	54.7	0	
206.7	206.6	54.1	54.2	1	Shale
207.3	206.7	53.5	54.1	0	
207.4	207.3	53.4	53.5	1	High rockface
208.0	207.4	52.8	53.4	2	Bedrock cut
208.1	208.0	52.7	52.8	0	
208.4	208.1	52.4	52.7	1	Truck ramp
209.2	208.4	51.6	52.4	0	Trees
209.5	209.2	51.3	51.6	1	Large cut slope; wide shoulder
209.8	209.5	51.0	51.3	1	Debris flow; rock buttress
210.0	209.8	50.8	51.0	0	
210.1	210.0	50.7	50.8	1	Wide shoulder
210.6	210.1	50.2	50.7	1	Trees
211.0	210.6	49.8	50.2	2	
211.2	211.0	49.6	49.8	3	Old mud and rock problem
211.5	211.2	49.3	49.6	2	Jersey barriers; surface runoff problems
211.7	211.5	49.1	49.3	0	Truck ramp
211.9	211.7	48.9	49.1	2	Bedrock outcrop
212.5	211.9	48.3	48.9	3	
212.7	212.5	48.1	48.3	4	
212.8	212.7	48.0	48.1	1	
213.0	212.8	47.8	48.0	3	High talus slope
213.3	213.0	47.5	47.8	4	High talus slope, no shoulder
213.5	213.3	47.3	47.5	0	
215.3	213.5	45.5	47.3	0	Eisenhower Tunnel
215.6	215.3	45.2	45.5	0	
215.9	215.6	44.9	45.2	2	Cut slope, no shoulder
217.7	215.9	43.1	44.9	0	Junction Loveland Pass
218.0	217.7	42.8	43.1	1	Bethel snowslide
219.7	218.0	41.1	42.8	0	Trees

Table 3. Continued.

BEGINNING MILEPOST	END MILEPOST	BEGINNING MILES	END MILES	RATING	REMARKS
220.0	219.7	40.8	41.1	1	Good cut slope of loose material
220.4	220.0	40.4	40.8	0	
220.7	220.4	40.1	40.4	1	Rockface; wide shoulder
221.0	220.7	39.8	40.1	0	Wide shoulder
221.1	221.0	39.7	39.8	1	
221.7	221.1	39.2	39.7	0	Bakerville
221.7	221.7	39.1	39.2	1	Rockface
221.8	221.7	39.0	39.1	0	Depression
222.2	221.8	38.6	39.0	1	Rockface; wide shoulder
223.0	222.2	37.8	38.6	0	
223.1	223.0	37.7	37.8	1	Loose sand and rocks
223.3	223.1	37.5	37.7	0	Wide shoulder
223.4	223.3	37.4	37.5	1	Small roadcut
224.3	223.4	36.5	37.4	0	
224.4	224.3	36.4	36.5	3	Groundwater in rockface
224.5	224.4	36.3	36.4	2	Groundwater in rockface
225.9	224.5	34.9	36.3	0	Silver Plume
226.0	225.9	34.8	34.9	1	Earth berm
226.3	226.0	34.5	34.8	4	High wall
226.5	226.3	34.3	34.5	3	Wide shoulder
227.0	226.5	33.8	34.3	4	Needs scaling
227.1	227.0	33.7	33.8	1	Guardrail, waterfall
227.7	227.1	33.1	33.7	4	High wall rockface
229.0	227.7	31.8	33.1	0	Georgetown
229.3	229.0	31.5	31.8	1	Old landslide, benched
229.4	229.3	31.4	31.5	0	Large drainage
229.5	229.4	31.3	31.4	2	Guardrail, fence
229.6	229.5	31.2	31.3	1	
229.7	229.6	31.1	31.2	1	Rockface
230.0	229.7	30.8	31.1	2	Sandy talus
230.7	230.0	30.1	30.8	1	Wide shoulder
235.6	230.7	25.2	30.1	0	Dumont, Lawson
235.7	235.6	25.1	25.2	2	Rockface
235.8	235.7	25.0	25.1	0	Large shoulder
235.9	235.8	24.9	25.0	1	Rockface
236.0	235.9	24.8	24.9	0	Wide shoulder
236.4	236.0	24.5	24.8	2	Rockface
236.4	236.4	24.4	24.5	0	Bridge
236.5	236.4	24.3	24.4	3	Rockface
236.7	236.5	24.1	24.3	0	Colluvium
236.8	236.7	24.0	24.1	2	Rockface, loose boulders
236.9	236.8	23.9	24.0	1	Rockface
237.0	236.9	23.9	23.9	0	
237.0	237.0	23.8	23.9	4	Outcrop over road
237.2	237.0	23.6	23.8	3	Talus rock and sand problem
237.4	237.2	23.4	23.6	1	High wall rockfall fence
237.7	237.4	23.1	23.4	1	Fall River Road
237.9	237.7	22.9	23.1	0	Bridge
238.7	237.9	22.1	22.9	2	Rockface
241.0	238.7	19.8	22.1	2	

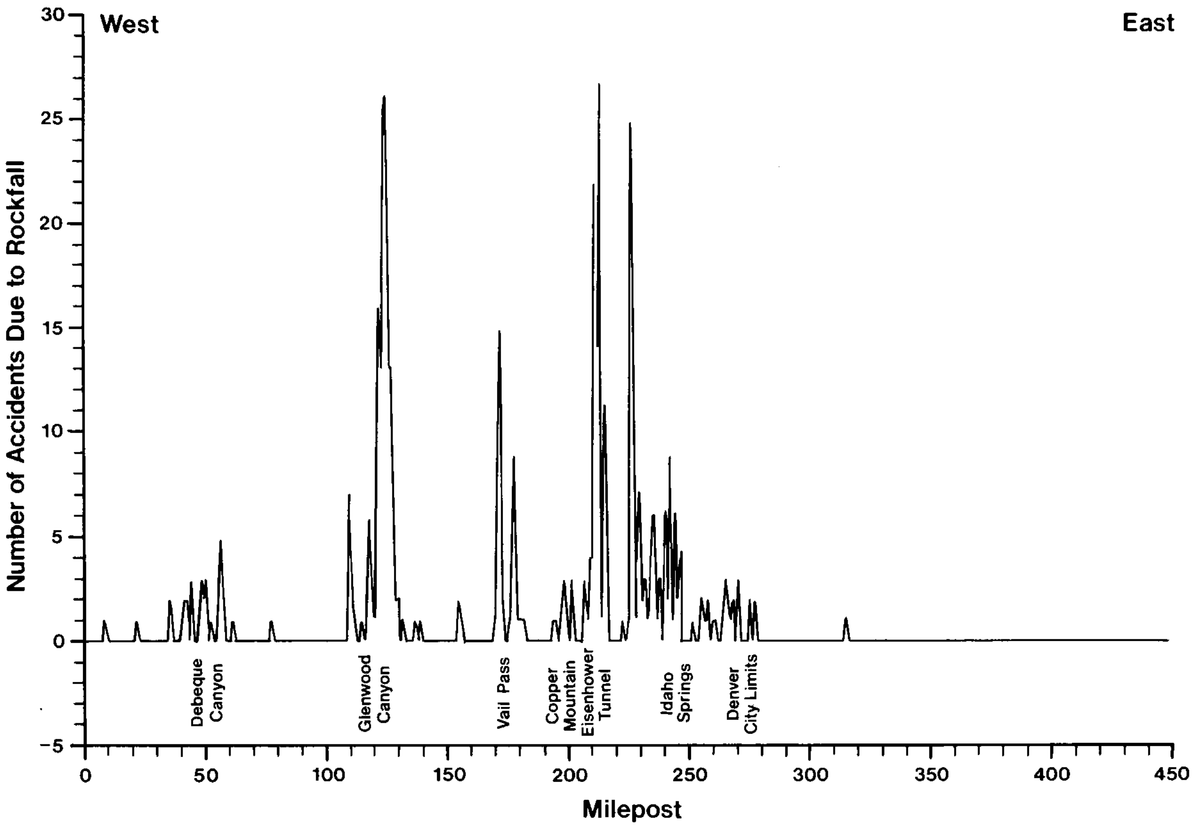

Figure 1. Number of vehicle accidents attributed to rockfall on Interstate 70 (1976–1989).

Those road segments shown as having a high rating by CDOH maintenance workers, but no indication of accidents due to rockfall should become secondary targets for Phase II assessment. An example of a secondary target area is shown in Figure 2 between mileposts 204 and 209 from Silverthorne to 5 miles east of Silverthorne.

Note that the rockfall hazard can be considered as having been mitigated for those road segments which are shown as having accidents, but were not identified as hazardous areas by CDOH maintenance personnel. For example, 22 accidents attributed to rockfall occurred within mile 211 on the west side of the Eisenhower Tunnel during 1976 through 1989. However, the recent installation of Jersey barriers along this segment of road has decreased the hazard considerably and this road segment is thus a low priority for evaluation in Phase II of this study. Caution should be used however, in determining the length of time and familiarity a particular individual maintenance worker has with a given section of road. For example, the maintenance employee may not be aware of several accidents or maintenance problems which occurred at a given point prior to his assignment to that road, but which have not recurred since. He could thus identify it as not hazardous, while CRASH shows it as having a past rockfall accident history.

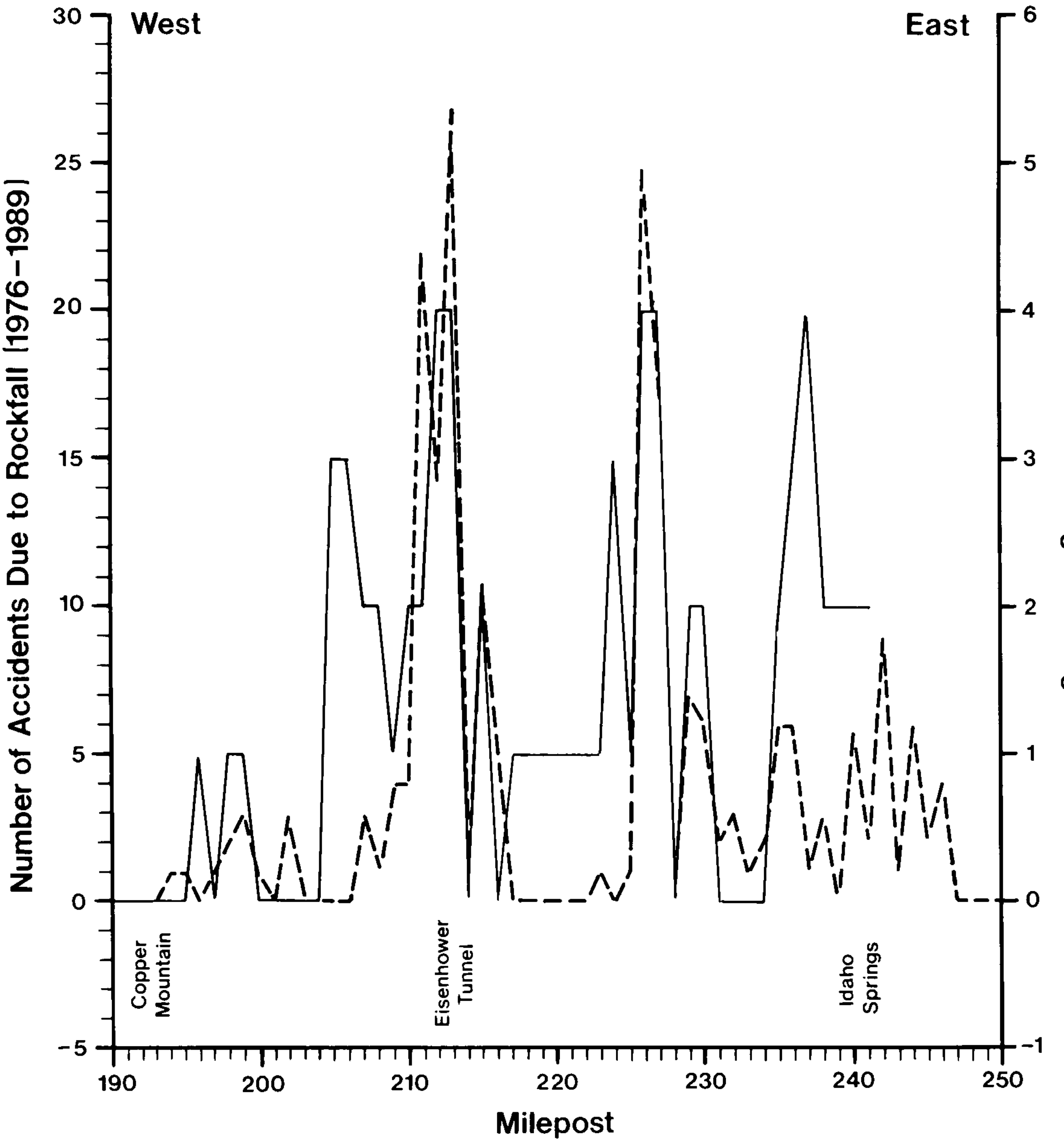

Figure 2. Number of accidents attributed to rockfall and rockfall-prone locations identified by CDOH Maintenance Department, Idaho Springs to Copper Mountain along Interstate 70 in Colorado. Dashed line is crash data, solid line is drive through ranking.

Phase 2: Site Specific Hazard Rating System

PURPOSE AND APPROACH

The purpose of this phase of the project was to modify or adopt existing site specific rockfall hazard rating systems in use in other areas for Colorado. Using our approach, the CRASH computer program and maintenance ride throughs identify and rank those points or sections of a given highway which have chronic rockfall problems and numerous accidents. Geologists are directed to individual points or mileposts by information from CRASH and evaluate the slopes, geologic factors, climate and ground water, and physical settings of each rockfall source area using the rating system. The function of the site specific rating system then becomes to further delineate, describe, and score individual rockfall source areas or sites within the sectors identified by CRASH, and to collect preliminary geologic and physical site data. The evaluation and scoring criteria in our prototype system is also used to define distinct segments with similar geologic, slope, and rockfall criteria within long stretches of rockfall prone highways such as those found in canyons and on mountain passes. These segments can then be scored, and mitigation work tailored to their specific geologic and physical aspects, with the most hazardous receiving attention first.

Data Sources

Existing rockfall hazard rating systems were obtained for evaluation in the field in Colorado. These included the New York Department Of Transportation's Rock and Earth Slope Evaluation Program, Rock slope Inventory/Maintenance Programs by Golder Associates, (Seattle, Washington; Vancouver, British Columbia), and the Oregon Department of Transportation (ODOT) Rockfall Hazard Ranking System. Each system was similar in that it assigned scores for a varying degree of severity of an identified rockfall parameter. The scoring forms for each system were remarkably similar.

While all three of these existing systems are directed more toward hazards associated with rock cuts and constructed rock slopes along highways, the ODOT system was most adaptable for scoring natural rockfall from the cliffs, steep slopes, and canyon walls commonly found above many highways in Colorado. We settled on the ODOT system, for its adaptability and detail in its discussion and characterization of the various categories. The ODOT system is shown in Figure 3.

ODOT Rockfall Hazard Rating System

After using the ODOT system and forms in the field, we made several modifications to adapt the rating system and forms to our two-phase hazard identification approach. The first was to eliminate the highway design categories of sight distance, roadway width, traffic ADT, ditch dimensions, and average yearly maintenance costs. This was done for several reasons: 1) At this phase in our approach, the site has already been identified as a rockfall hazard site by the CRASH program and maintenance. Many of the criteria such as site distance and road width are thus factored into the accident count which has directed the engineering geologists to the site. 2) These geologists generally are not familiar with nor experienced enough to make highway design judgments such as sight distance design values or the Ritchie criteria for ditch dimensions. 3) Maintenance input is already incorporated before the site is visited for scoring. 4) Additional research through highway design records and maintenance cost data for each site

ODOT Rockfall Hazard Rating System						
CATEGORY			RATING CRITERIA AND SCORE			
			Points 3	Points 9	Points 27	Points 81
Slope Height			25 ft	50 ft	75 ft	100 ft
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 Shoulder			44 ft	36 ft	28 ft	20 ft
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 slicken-sided
	CASE 2	Structural Condition	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
		Difference in Erosion Rates	Small	Moderate	Large	Extreme
Block size / Quantity of Rockfall / Event			1 ft / 3 cu yd	2 ft / 6 cu yd	3 ft / 9 cu yd	4 ft / 12 cu yd
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 periods or continual water on slope and long freezing periods
Rockfall History			Few falls	Occasional falls	Many falls	Constant falls

Figure 3. Summary sheet of the ODOT rockfall hazard rating system.

would be required before scores could be calculated.

Modifications were also made to the layout of the forms. We provided spaces for detailed location identification information on each form as well as space to cross reference referrals from the maintenance ride throughs. Also added was space for recording field measurements and observations directly on the scoring forms themselves. An example of the modified system and form we used in the study are shown in Figures 4 and 5.

ODOT System Adaptation

Shortcomings were discovered using the preliminary ODOT system during field testing. These included omission of pertinent rockfall hazard ranking criteria such as evidence of water seepage on the slopes, slope inclination, and provisions for rockfalls from unconsolidated deposits such as till and gravel banks. During the course of this project, the final version of the ODOT system became available. The criteria we felt were missing and had added to our ranking system were found to be incorporated into the revised ODOT system, specifically through more detailed descriptions and added text which guided the investigator more effectively in assigning scores in the various categories.

DISCUSSION

Our experience with the ODOT system indicates that the geotechnical categories and ranking scheme work reasonably well. It allows the geologist a fair degree of latitude in evaluating the merits of conditions which are highly variable in the field. The progression of points to be scored allows a good range of flexibility for individual situations. Our pilot study uses the system for assigning scores for ranking rockfall sources on a site specific basis, and as criteria for defining individual segments within long stretches of rockfall prone highway. This aids in differentiating between adjacent slopes which may require specifically designed and/or different mitigation approaches.

We believe that the CDOH should adopt the ODOT rating system for geologic and geotechnical rockfall categories. The ODOT system is entirely compatible with the slightly modified forms we developed during the pilot study. The final version of the ODOT Rockfall Hazard Rating System is now available from ODOT.

Rockfall Hazard Rating System						
FACTOR			RANK			
			3 Points	9 Points	27 Points	81 Points
SLOPE PROFILE	Slope Height		25 to 50 ft	50 to 75 ft	75 to 100 ft	100 ft
SLOPE PROFILE	Segment Length		0 to 250 ft	250 to 500 ft	500 to 750 ft	750 ft
SLOPE PROFILE	Slope Inclination		15 to 25 degrees	25 to 35 degrees	35 to 50 degrees	50 degrees
SLOPE PROFILE	Slope Continuity		Possible launching features	Some minor launching features	Many launching features	Major rock launching features
GEOLOGIC CHARACTERISTICS	Average Block or Clast Size		6 to 12 in.	1 to 2 ft	2 to 5 ft	5 ft
GEOLOGIC CHARACTERISTICS	Quantity of Rockfall Event		1 cu ft to 1 cu yd	1 to 3 cu yds	3 to 10 cu yds	10 cu yds
GEOLOGIC CHARACTERISTICS	CASE 1	Structural Condition	Discontinuous fractures, favorable orientation	Discontinuous fractures, random orientation	Discontinuous fractures, adverse orientation	Continuous fractures, adverse orientation
GEOLOGIC CHARACTERISTICS	CASE 1	Rock Friction	Rough, irregular	Undulating smooth	Planar	Clay, gouge infilling, or slickensided
GEOLOGIC CHARACTERISTICS	CASE 2	Structural Condition	Few differential erosion features	Occational erosion features	Many erosion features	Major erosion features
GEOLOGIC CHARACTERISTICS	CASE 2	Difference in Erosion	Small difference	Moderate difference	Large difference	Extreme difference
Climate and Presence of Water on Slope			Low to moderate precipitaion; no feezing 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 (From Ride Through)			Few falls	Occasional falls	Many falls	Constant falls
Number of Accidents Reported in Mile			0 to 5	5 to 10	10 to 15	15 and over

Figure 4. Colorado rockfall hazard rating system.

Rockfall Hazard Rating Worksheet

Project ______________________ Priority ______________________

Date ______________________ M. P. ______________________

Highway ______________________ Segment __________ of __________

Geologist ______________________ Segment I. D. No ______________________

<table>
<tr><th colspan="3">CATEGORY</th><th>DESCRIPTION</th><th>SCORE</th></tr>
<tr><td colspan="3">Slope Height</td><td></td><td></td></tr>
<tr><td colspan="3">Segment Length</td><td></td><td></td></tr>
<tr><td colspan="3">Slope Inclination</td><td></td><td></td></tr>
<tr><td colspan="3">Slope Continuity</td><td></td><td></td></tr>
<tr><td colspan="3">Block Size</td><td></td><td></td></tr>
<tr><td colspan="3">Quantity Per Event</td><td></td><td></td></tr>
<tr><td rowspan="4">GEOLOGIC CHARACTER*</td><td rowspan="2">CASE 1</td><td>Structural Condition</td><td></td><td></td></tr>
<tr><td>Rock Friction</td><td></td><td></td></tr>
<tr><td rowspan="2">CASE 2</td><td>Structural Condition</td><td></td><td></td></tr>
<tr><td>Difference in Erosion Rate</td><td></td><td></td></tr>
<tr><td colspan="3">Precipitiation / Climate
Presence of Water</td><td></td><td></td></tr>
<tr><td colspan="3">Rockfall History
From Ride Through</td><td></td><td></td></tr>
<tr><td colspan="3">Number of Accidents
Reported in Mile</td><td></td><td></td></tr>
<tr><td colspan="3"></td><td>Total Score</td><td></td></tr>
</table>

* For this category, rate either Case 1 or Case 2.

Figure 5. Colorado rockfall hazard rating worksheet.

SECTION 2
PROCEDURES MANUAL FOR IMPLEMENTATION OF THE COLORADO HIGHWAY ROCKFALL HAZARD EVALUATION SYSTEM

PURPOSE AND APPROACH

PURPOSE

This manual describes the systematic phased approach to identifying and evaluating highway rockfall hazard areas using the prototype Colorado Highway Rockfall Hazard Evaluation System. It is intended to be a resource document for rockfall hazard evaluation using the system developed from the Pilot Highway Rockfall Hazard Research Project Report.

APPROACH

The Colorado Highway Rockfall Hazard Evaluation System is a systematic stepped approach which is designed to identify and evaluate hazardous highway rockfall sites over large sections of highway in a cost effective manner. The steps are:

PROCEDURE FOR IDENTIFICATION OF ROCKFALL PRONE AREAS

1. Run the Colorado Rockfall Accidents on State Highways (CRASH) computer program on the highway, district, or section of highway under investigation.
2. Conduct a ride through with the maintenance foremen over the segments of highway under investigation, noting identified rockfall areas, and scoring maintenance input using the ODOT system criteria.
3. Compare the problem areas from the ride throughs with those generated by CRASH.
4. Develop a "priority list" of sites for further detailed evaluation.

SITE SPECIFIC FIELD EVALUATION

1. Dispatch engineering geologists to conduct detailed evaluation and scoring of the sites identified in steps one and two above.
2. Assemble the scored site forms, field data and remedial approach recommendations for presentation to management.

Procedure for Identification of Rockfall–Prone Areas

STEP 1: RUN CRASH PROGRAM

Run the CRASH computer program on the highway or area under investigation. Input from management should guide the decision as to which highways, sections of highways, or districts are to be inventoried. This may depend on budgetary constraints as well as existing construction or maintenance projects slated for certain areas. In many cases, a cost savings can be realized by scheduling rockfall remediation work during other maintenance or construction activity.

The output from the CRASH run should be in tabular form as well as a plot of number of rockfall accidents by mile marker. The plots make comparison of data from the ride through rankings easier. The table of accident counts per mile marker is the preliminary "Action List" of sites for further study.

STEP 2: CONDUCT MAINTENANCE DRIVE THROUGHS

Assign a geologist to ride on patrol with maintenance foremen through all the sections of highway which were put through the CRASH identification program in step one. The geologist must make notes of all rockfall areas known to the maintenance foreman, as well as their mile markers. This information represents the best approximation of known rockfall activity on a given stretch of highway. A score or rank for severity of the rockfall problem at a given site is assigned according to the foreman's experience using, the ODOT categories as follows:

1 point—No Rockfall History.

3 points—Few Falls. Rare minor rockfalls. Rockfall is not frequent enough or large enough to be a significant problem, but historic information indicates that some rocks reach the road on rare occasions.

9 points—Occasional Falls. Rockfalls have occurred several times in the past, but they are 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.

27 points—Many Falls. Rockfall occurs frequently. Rockfall can be expected several times per year and during most storms. This category is for sites that are frequent but not constant rockfall problems.

81 points—Constant Falls. Rockfalls reach the road several times a week during most of the year. This category is for severe cases where rockfall occurs on an almost daily basis.

Up to date information on new remediation measures must also be noted. For example, if a new section of barriers was recently installed to control rockfall, past accident data from CRASH may point to the site as being a problem, while maintenance input considers it minor or "solved". It is extremely important that this information be collected. Ideally a tape recorder or video recorder should be used to collect this information during the ride through so that no pertinent facts regarding rockfall hazards are missed. It is also convenient to note the locations of each site in tenths of miles from the vehicle odometer for future reference.

Information gathered during the ride through is entered on a score sheet so that maintenance input becomes a permanent part of the record.

STEP 3: ANALYZE ROCKFALL HAZARD LOCATION INFORMATION

After the ride through program has been conducted, the maintenance input data should be combined with the CRASH output locations. This is done by entering the maintenance rankings by milepost off the ride through score sheets. The combined data can then be plotted and analyzed to determine primary target sites for detailed Phase II evaluation work.

Highway segments which have a high CRASH accident count and a high rockfall frequency rating from maintenance should be considered primary sites for further evaluation. The fact that many accidents occur despite the intensive maintenance indicates a high priority problem site.

Sections of road which are identified as having high occurrences of rockfalls from maintenance, but no reported accidents, should be considered as secondary sites. These areas commonly are the nuisance types of rockfall problems. Although they drain maintenance budgets, the character of the highway and/or the small sizes of the rocks are such that rockfall is not causing accidents, or any accidents that are caused are apparently not serious enough to be reported.

Caution should be used when making this assumption in remote rural areas. There may be a significant number of minor accidents which cause damage to vehicles, but are not being reported due to a long response time for a highway patrol officer to get to the site. A judgment based on information obtained from the local patrols and maintenance foreman should be made to determine if such a situation warrants being considered a primary target site.

If the CRASH data indicates numerous past accidents, but maintenance input does not show a problem at that location, it may indicate that remediation measures have been constructed. An examination of the accident records in comparison to when the mitigation was completed will give an indication of how effectively the mitigation has been working. If it appears that mitigation efforts are controlling the rockfall, these sites should be eliminated, or considered as lower priority sites.

STEP 4: COMPILE "PRIORITY LIST"

This step involves selecting the areas identified above for further site specific evaluation and rating. If desirable, the list of high priority sites may be compiled in coordination with management so that economies associated with ongoing maintenance or construction projects can be incorporated into planning at this stage. Cost savings can be made if high priority sites are scheduled for mitigation work in conjunction with existing or planned maintenance or construction projects, even if they are not highest on the list. This may be an important factor to consider in light of recent tight budgets.

Management also needs to be consulted as to how large a field evaluation project is warranted at a given time. Depending on budget allowances for rockfall control, projects may vary in size and scope from year to year. The available dollars may only be enough to address a few sites per year, so it is important to decide how many sites should receive further detailed field evaluation. This will influence how far down the list of priority sites field work will proceed during a given project.

DETAILED FIELD EVALUATION

STEP 1: CONDUCT SITE SPECIFIC EVALUATION AND HAZARD RATINGS

Approach

Engineering geologists are directed to the highest priority rockfall sites identified from the priority list generated above. They are not bogged down with trying to figure out where to begin, or which sections of a canyon have the worst rockfall hazards. They are able to zero in on the sites which, if mitigated, would result in the greatest reduction in accidents. This approach saves on travel costs and man hours.

Equipment

The geologist should be provided with a table listing the sites to be evaluated called out by milepost or increment from (CRASH), and copies of the ride through score sheets for those same locations. Equipment required includes the following: 1) a safety vest, 2) hard hat, 3) a measuring wheel, 4) a clipboard with rating forms and ODOT rating system criteria, 5) topographic map of the area, 6) field notebook, 7) 12 foot steel tape measure, 8) can of silver spray paint, 9) Brunton compass or slope inclinometer, 10) a camera, (preferably one with a date recording attachment), 11) this "Procedures Manual".

Procedure

Upon reaching the milepost or point called out, a brief ride should be taken through the segment moving in a direction from lower to higher mile marker. This reconnaissance will serve to judge how many potential rockfall hazard segments will be defined in the section of highway to be evaluated. In many cases, there will only be one or two possible rockfall sites within the segment. In these instances the geologist can quickly zero in on the hazardous sites and begin the evaluation process.

In winding mountain canyons or on mountain pass approaches, there may be numerous potential rockfall hazards all along the entire mile or reach to be evaluated. In this case the geologist must use the information from the ride through score sheet to zero in on the worst area, or alternatively, break the stretch down into discrete segments and score each one. If there is any doubt as to the location referred to in the ride through data, it is preferable to evaluate the whole stretch of highway.

Delineation of Segments

Each part of the stretch of highway to be evaluated should be examined and separated into segments. The segments should define a section of rockfall slope which has similar ODOT categories and geologic characteristics, such as rock type, jointing, dip, slope, height, and mode or mechanism of rockfall. ODOT categories should be used to define the boundaries of each segment from adjacent ones. For example, if there is a segment where large cobbles and boulders are being released from till, and next along the road is a cut through weathered schist and gneiss, separate segments would have to be delineated and scored on the till verses bedrock slope, because the geologic character is different. By the same token, a rock cut 40 feet high which suddenly juts up to 100 feet high would also dictate a segment boundary between the two heights, even though the geologic character of the cut is consistent. It is important to keep in mind what type of mitigation approach might be amenable to the problem area, as well as what engineering parameters will affect its design. This often will dictate where a segment boundary should be defined.

Measurement and Location of Segments

As each segment is defined, an identification number is assigned, and its begining and end points located and referenced to the mile in which it lies. This is done by noting the milepost plus X number of feet to the begining and end point of each segment using the measuring wheel. For example, segment "I-70-WB232 A" begins at mile 232 plus 345 feet and extends to mile 232 plus 412 feet on Interstate 70 west bound. The silver spray paint may be used to mark the boundaries between adjacent segments for future reference.

In areas where there are only one or two widely separated rockfall segments, it is permissible to locate the begining of each segment by noting the tenth of a mile on a vehicle odometer, however the length of the segment should be measured with the measuring wheel.

Scoring Segments Using ODOT Categories

Rockfall prone slopes are scored using the Rockfall Hazard Rating System. For each category a measurement, estimate, or judgment is made and recorded on the rating form in the appropriate score box. (Refer to the ODOT RHRS for detailed descriptions of each category and scoring criteria). The geologist should make notes of all pertinent rockfall features and observations used in scoring the various categories. Actual measurements of geologic rockfall factors such as slope height, slope angle, bedding thickness, and dip, joint orientation and character etc. which can be collected easily (without climbing) during the site evaluation. This data is useful in selecting remediation measures and can be used to guide preliminary cost estimating.

An additional catagory has been included, which incorporates CRASH data into the detailed rating system. This catagory has been added so that an overall risk assessment may be included in the score much the same as site distance and ADT information data.

Record of Site Visit

In addition to the rating forms, the geologist should keep a record of the site visit in a field notebook. This record should inlude the procedures used, weather conditions, time of day, traffic volume, and brief descriptions of each segment evaluated and scored. A location sketch of the relative positions of individual segments, and their assigned numbers should also be made. The locations of scored segments should also be plotted on topographic maps of as large a scale as available, commonly 1:24000 U.S. Geological Survey Quadrangle maps. (Figure 6.)

Photographing Segments

Each delineated and scored segment should be photographed in its entirety before leaving the field. Photographs should be made using a 35 millimeter camera with color print film, of ASA 64 to 100. The photographs should be composed so that a face-on view of the cut or slope is taken. If the slopes are very high, a 35 to 28 millimeter lens may be required to get the entire height of the cut or face in the frame. Photographs of each segment should proceed from beginning (lower mileage) to end of the segment with overlap between frames.

Some form of in-frame identifier must be used so that each photograph can be related to the proper segment. (After dozens of pictures of rock faces and slopes, they all look alike!) This is most easily accomplished using a camera with a date recording back. The segment number can thus be encoded into each photograph. Alternatively, some type of number board can be made up and positioned in each photograph as it is taken in the field, but this can be cumbersome. The final but least desirable alternative for identifying photographs is to keep a roll-by-roll, frame-by-frame log, however, unless done diligently and the slides labelled promptly, this method usually creates chaos.

STEP 2: PREPARE HAZARD REPORTS FOR MANAGEMENT TEAM ANALYSIS

Rating forms and data collected during field work must be assembled into reports for management analysis and decision making. These reports can be arranged by highway and district, or alternatively by highway and maintenance patrol section. Reports should include the CRASH output lists and plots, the maintenance ride through rating sheets, and the scored rockfall hazard rating forms.

A summary table of segment scores from highest to lowest with the locations of each segment should also be included, along with a brief rockfall hazard analysis and description of the highest priority sites. Appropriate mitigation strategies and recommendations are also desirable. All other geologic data and field book diaries should be kept in a working file for future reference during mitigation project planning and cost estimation.

Color prints made from the segment photo graphs should be included in the report in plastic sleeves. These should be arranged or labelled so that each segment can be viewed in its entirety. Copies of the topographic map sections with mile markers and segments plotted on them should also be included.

These reports become in effect the record of the CDOH systematic approach to identification and ranking of highway rockfall hazards. It is important that they be as complete and as accurate as possible. They will form the basis for directing rockfall hazard mitigation work toward those sites which present the greatest danger to the traveling public.

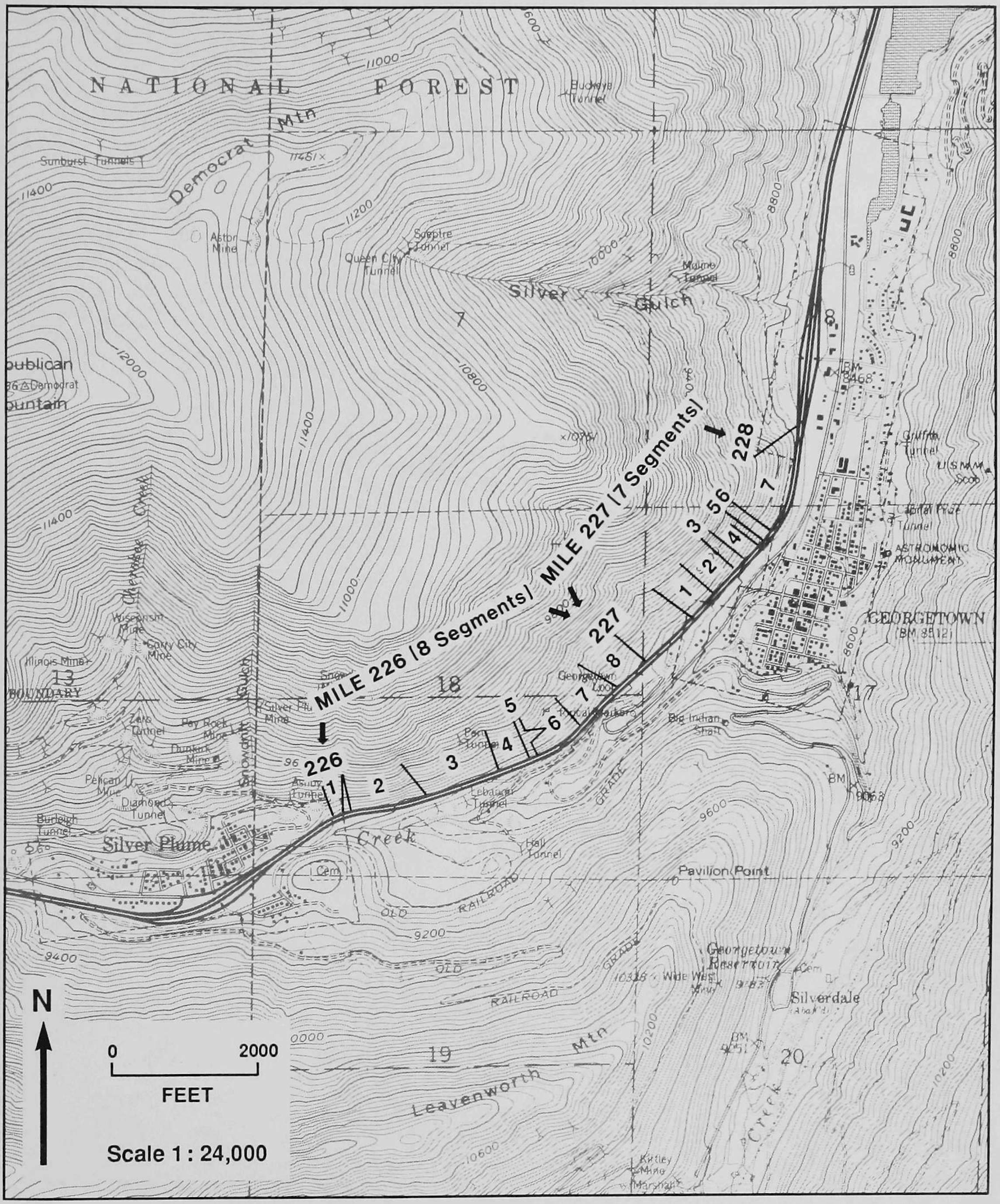

Figure 6. Sample site map showing mileposts and delineation of rockfall segments (U.S. Geological Survey Georgetown 7.5-minute quadrangle).