Alaska Department of Transportation & Public Facilities
Alaska University Transportation Center

Unstable Slope Management Program

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August 2009

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2301 Peger Road
Fairbanks, AK 99709-5399

INE/AUTC 11.18

DOT # FHWA-AK-RD-12-14

REPORT DOCUMENTATION PAGE			Form approved OMB No.
Public reporting for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-1833), Washington, DC 20503			
1. AGENCY USE ONLY (LEAVE BLANK) FHWA-AK-RD-12-14	2. REPORT DATE August 2009	3. REPORT TYPE AND DATES COVERED Final Report (07/2008-08/2009)	
4. TITLE AND SUBTITLE Unstable Slope Management Program			5. FUNDING NUMBERS AUTC # RR08.10 DTRT06-G-0011 T2-08-03
6. AUTHOR(S) Scott L. Huang, Ph.D. Margaret M. Darrow, Ph.D. Peter Calvin			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Alaska University Transportation Center P.O. Box 755900 Fairbanks, AK 99775-5900			8. PERFORMING ORGANIZATION REPORT NUMBER INE/AUTC 11.18
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Alaska Department of Transportation Research, Development, and Technology Transfer 2301 Peger Road Fairbanks, AK 99709-5399			10. SPONSORING/MONITORING AGENCY REPORT NUMBER FHWA-AK-RD-12-14
11. SUPPLENMENTARY NOTES			
12a. DISTRIBUTION / AVAILABILITY STATEMENT No restrictions			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) This Rapid Response Project gathered information on existing unstable slope management programs, with a focus on asset management practices in the United States and overseas. On the basis of this study, the research team summarized and recommended guidelines to develop an Unstable Slope Management Program for the ADOT&PF.			
14- KEYWORDS: Slope stability, Dislocation (Geology),			15. NUMBER OF PAGES 93 16. PRICE CODE N/A
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT N/A

NSN 7540-01-280-5500

STANDARD FORM 298 (Rev. 2-98)
Prescribed by ANSI Std. 239-18 298-1

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1 – INTRODUCTION

1.1 Background

Transportation corridors, depending on the geology and topography, will intercept unstable slopes and slope failures. These slope failures range in severity; some cause property damage and block traffic, while others go unnoticed by the general public. Although slope failures that cause significant blockages, property loss, or loss of life are not common, any slope failures along transportation corridors remain a thorny issue facing state transportation agencies, which are responsible for providing and maintaining safe routes with limited budgets.

Consistent with the federal efforts for overall disaster preparedness and risk reduction, many state transportation agencies are moving towards proactive risk management strategies for mitigating unstable slope issues (Rose 2005). With limited annual maintenance budgets, these agencies often are forced to decide the priority of remediation needs.

The identification and prioritization processes to deal with landslide, rockfall, and other slope failure prevention and remediation can be executed objectively only if an unstable slope management program that addresses the hazard and risk associated with unstable slopes is available. State transportation agencies increasingly have been investigating rockfall hazard management systems as a way to reduce risk to the traveling public and exposure of the agencies to civil penalties associated with rockfall events (Liang 2007).

The rating systems proposed by Pierson et al. (1990) and Maerz and Youssef (2004) focus on the rockfall/rock-cut hazard. These systems include such measures as geologic character, slope height and slope face condition, ditch geometry and effectiveness, vehicle risk, and decision sight distance. These methods consider hazard as part of risk without clearly identifying the distinction between the two.

The broader and more mature system of landslide risk assessment, on the other hand, does differentiate between risk and hazard. State transportation agencies in New York (NYSDOT 2007) and Utah (Pack and Boie 2002) implemented systems that incorporate risk assessment into a hazard rating system. Further incorporation of economic factors such as maintenance costs and detouring allows state transportation officials to treat cut slopes along roadways as an asset. Several states, including Washington (WSDOT 1995), Oregon (Pierson et al. 2001), and Ohio (Liang 2007) have used this approach in their unstable slope programs.

The Alaska Department of Transportation & Public Facilities (AKDOT&PF) is responsible for 5,606 miles of existing roads that traverse through areas of complex geology and varying terrain, much of which contains unstable slopes. The hazards derived from these unstable slopes include rock falls, soil and rock slides, and debris flows, among other forms of failure. Due to its northern location, Alaska also has accelerated mechanical weathering due to a high number of yearly freeze/thaw cycles and the presence of permafrost throughout most of the state, which results in unique slope instabilities due to melting ground ice. The failure of any of these unstable slopes poses a risk to the traveling public, causes damage to a wide range of transportation assets (e.g. pavement, retaining structures, guardrails, road signs, etc.), and adversely affects regional commerce due to the resulting highway closures.

1.2 Objectives

Recognizing the growing importance of asset management as related to unstable slopes, AKDOT&PF tasked this research team with providing information and recommendations upon which more effective resource allocation and a utilization management program can be based.

The objectives of this study are: 1) to gather information on existing unstable slope management programs with focus on asset management practices in the United States and overseas; and 2) to recommend guidelines for an AKDOT&PF Unstable Slope Management Program. The long-term goals of this study are eventually to implement and manage an effective unstable slope management program within AKDOT&PF and develop continuing funding sources through federal and/or state budget processes.

This study consisted of three tasks:

- Identifying and assessing unstable slope management programs in other states (e.g. Washington, Oregon, New York, and Utah) and countries with similar climatic conditions and terrains such as Canada and Norway.
- Identifying and comparing key successful and unsuccessful aspects of the programs both from an asset management viewpoint and from a technical viewpoint.
- Recommending guidelines for an AKDOT&PF Unstable Slope Management Program. These guidelines include identification of participating divisions within AKDOT&PF and their responsibilities, types of information required, and the sequential steps to implement the program.

CHAPTER 2 – REVIEW OF UNSTABLE SLOPE MANAGEMENT PROGRAMS

The unstable slope management programs implemented by many state transportation agencies have changed the mitigation approach for rockfall/landslide hazards along transportation corridors. Most of the hazard rating systems developed by or for individual state transportation agencies have been based largely on the method developed by Pierson et al. (1990). Subsequent modifications to the original Pierson method provide a closer link between hazard and risk, with an overall goal of prioritizing unstable slopes for remediation.

As of 2005, unstable slope management programs were in use in ten states and four countries, prioritizing unstable slopes for remediation (Rose 2005). Efficient management of unstable slopes is difficult, however, due to the broad range of conditions related to rockfall/landslide hazards and limited budgets for remediation. Nonetheless, most of the programs were developed to meet the needs of individual state transportation agencies by providing a quantitative assessment of hazard and risk potential. The sites with high scores based on a set of criteria and weighting values are priorities for remediation. Several of these existing unstable slope management systems are summarized in the following sections.

2.1 Oregon DOT-I (ODOT I)

In 1985, one of the Oregon Department of Transportation's regions began to inventory its highways to document where potential rockfall areas existed. This study led to a more proactive and rational approach in making informed decisions on where and how to spend construction funds. In late 1980s, the Rockfall Hazard Rating System (RHRS) developed by the Oregon Department of Transportation (ODOT) contains six main features (Pierson et al. 1990):

1. A uniform method for slope inventory
2. A preliminary rating of all slopes
3. The detailed rating of all hazardous slopes
4. A preliminary design and cost estimate for most serious sections
5. Project identification and development
6. Annual review and update

The RHRS computes hazard ratings based on ditch effectiveness, risk to vehicles, geologic and hydrologic characteristics, roadway width, slope height, and rockfall history. In addition, the system incorporates maintenance costs for each site. It includes two phases of surveys: the initial assessment phase (i.e. preliminary rating) as part of the statewide slope survey, and the detailed rating phase (Pierson et al. 1990).

The preliminary survey groups the rockfall sites inspected during the slope inventory into three broad categories. The rating is subjective, however, and requires experienced personnel to make sound judgments. See Table 2.1 for the criteria used in the preliminary rating.

The rating of the "Estimated Potential for Rock on Roadway" involves consideration of: 1) estimated size of material; 2) estimated quantity of material per event; 3) amount available; and 4) ditch effectiveness. The four items that are considered when rating the "Historical Rockfall

Table 2. Preliminary Rating System (taken from Pierson et al. 1990)

Criteria	Class		
	A	B	C
Estimated Potential for Rock on Roadway	High	Moderate	Low
Historical Rockfall Activity	High	Moderate	Low

Activity" are: 1) frequency of rockfall on highway; 2) quantity of material; 3) size of material; and 4) frequency of clean out (Pierson et al. 1990).

As the slopes along the state highway systems are recorded, each of the slope sites is classified with the following criteria:

1. Rating A: The slope displays evidence of active displacement and has a very limited fallout area.
2. Rating B: Rockfall is possible, but the frequency is low enough or the fallout area is large enough.
3. Rating C: It is unlikely that a rock will fall at the site or if one should fall it is unlikely that it will reach the roadway.

The RHRS requires all slope sections receiving either an "A" or "B" preliminary rating to be rated with the upper part of the Rockfall Hazard Field Data Sheet (see Figure A.1). This collected information details the location and frequency of rockfall activity, size/quantity of rockfall per event, type of rockfall material, accident history, frequency of clean out, cost of maintenance, etc.

All of the "A" rated slopes and a few "B" rated slopes are further evaluated with a detailed rating system (see Figure A.1). The detail rating covers 12 different categories, including slope height, ditch effectiveness, average vehicle risk, percent decision sight distance, roadway width, geologic characteristics, block size or quantity of rockfall per event, climate and presence of water in slope, and rockfall history. Each of these factors indicates a certain degree of potential hazard in a slope. Table 2.2 is the Summary Sheet, which includes all of the categories and their rating. The exponential scoring system with four breaks (i.e. 3, 9, 27, and 81) represents a continuum of scores from 1 to 100. The total score of the 12 categories represents the overall risk of a rockfall location. The exponential scoring system allows a quick identification of the more hazardous sites through the wide range of numeric scores (Pierson et al. 1990). The following is a summary of the category narratives that accompany Table 2.2:

1. Slope Height - The slope height is the vertical distance from the bottom of the slope to the highest point at which rockfall is expected. If rocks are from the natural slope above the cut, the slope height is the cut slope height plus the additional vertical height in the natural slope.

Table 2. Summary Sheet of the Rockfall Hazard Rating System (taken from Pierson et al. 1990)

<table>
<tr><th colspan="3" rowspan="2">Category</th><th colspan="4">Rating Criteria and Score</th></tr>
<tr><th>3 Points</th><th>9 Points</th><th>27 Points</th><th>81 Points</th></tr>
<tr><td colspan="3">Slope Height</td><td>25 ft</td><td>50 ft</td><td>75 ft</td><td>100 ft</td></tr>
<tr><td colspan="3">Ditch Effectiveness</td><td>Good Catchment</td><td>Moderate Catchment</td><td>Limited Catchment</td><td>No Catchment</td></tr>
<tr><td colspan="3">Average Vehicle Risk</td><td>25% of the time</td><td>50% of the time</td><td>75% of the time</td><td>100% of the time</td></tr>
<tr><td colspan="3">Percent of Decision Sight Distance</td><td>Adequate sight distance, 100% of low design value</td><td>Moderate sight distance, 80% of low design value</td><td>Limited sight distance, 60% of low design value</td><td>Very limited sight distance, 40% of low design value</td></tr>
<tr><td colspan="3">Roadway Width Including Paved Shoulders</td><td>44 ft</td><td>36 ft</td><td>28 ft</td><td>20 ft</td></tr>
<tr><td rowspan="4">Geologic Character</td><td rowspan="2">Case 1</td><td>Structural Condition</td><td>Discontinuous joints, favorable orientation</td><td>Discontinuous joints, random orientation</td><td>Discontinuous joints, adverse orientation</td><td>Continuous joints, adverse orientation</td></tr>
<tr><td>Rock Friction</td><td>Rough, Irregular</td><td>Undulating</td><td>Planar</td><td>Clay infilling, or slickensided</td></tr>
<tr><td rowspan="2">Case 2</td><td>Structural Condition</td><td>Few Differential erosion features</td><td>Occasional differential erosion features</td><td>Many differential erosion features</td><td>Major differential erosion features</td></tr>
<tr><td>Difference in Erosion Rates</td><td>Small Difference</td><td>Moderate Difference</td><td>Large Difference</td><td>Extreme Difference</td></tr>
<tr><td colspan="3">Block Size or
Quantity of Rockfall Per Event</td><td>1 ft
3 cubic yards</td><td>2 ft
6 cubic yards</td><td>3 ft
9 cubic yards</td><td>4 ft
12 cubic yards</td></tr>
<tr><td colspan="3">Climate and Presence of Water on Slope</td><td>Low to moderate precipitation; no freezing periods; no water on slope</td><td>Moderate precipitation or short freezing periods or intermittent water on slope</td><td>High precipitation or long freezing periods or continual water on slope</td><td>High precipitation with long freezing periods or continual water on slope and long freezing periods</td></tr>
<tr><td colspan="3">Rockfall History</td><td>Few Falls</td><td>Occasional Falls</td><td>Many Falls</td><td>Constant Falls</td></tr>
</table>

2. Ditch Effectiveness – Ditch effectiveness is a subjective score based on (1) slope height and angle; (2) ditch width, depth, and shape; (3) anticipated block size and quantity of rockfall; and (4) impact of slope irregularities on falling rocks. For good catchment (Score = 3), almost all of the falling rocks are contained in the ditch; moderate catchment (Score = 9) indicates that falling rocks occasionally reach the roadway; limited catchment (Score = 27) is the condition in which falling rocks frequently reach the roadway; and no catchment (Score = 81) allows all or nearly all falling rocks to reach the roadway.

3. Average Vehicle Risk (AVR) – Average vehicle risk measures the percentage of time that a vehicle will be present in the rockfall section. The AVR is determined by multiplying the average daily traffic (ADT) by the length of the rockfall section in miles

and then by 100% to give a percentage. This is further divided by the posted speed limit (mph) and again by 24 hours per day. The category score is calculated by $3^{(AVR/25)}$.

4. Percent of Decision Sight Distance (DSD_%) – The decision sight distance (DSD) is the distance in feet that a 6-inch object is visible to a driver along the roadway. The DSD then is divided by AASHTO's decision sight distance in feet for the posted speed limit in miles/hour, and multiplied by 100% to give a percentage. The category score is calculated as $3^{(120 - DSD\_\%)/20)}$.
5. Roadway Width – The roadway width is measured in feet perpendicular to the roadway centerline from edge to edge of the paved section. The ditch and unpaved shoulders are not included. The category score is calculated by $3^{((52 - width)/8)}$.
6. Geologic Character (Case 1) – The geologic conditions are evaluated based on the dominance of discontinuities or differential erosion. Case 1 is for slopes where discontinuities (e.g. joints, bedding, foliation, etc.) are the dominant structural features. The structural condition in Case 1 evaluates how joints in rock adversely affect the stability of a slope. Joints are divided based on length and orientation into sub-groups: discontinuous (< 10 ft in length) and continuous (> 10 ft in length), favorable, random, and adverse orientation. Adverse joints cause plane, wedge, or toppling failures. Rock friction is an indication of the potential for a block to move. The friction characteristics of the joints are based on the degree of interlocking (i.e. joint surface roughness and joint plane waviness) and infilling. Rough and irregular joints (Score = 3) have rough joint surface and irregular joint planes that cause interlocking. Undulating joints (Score = 9) have rough joint surface and joint planes but without interlocking. Planar joints (Score = 27) have rough joint surfaces and smooth joint planes. Friction is strictly from the roughness of the joint surface. Joints with clay infilling or slickensided (Score = 81) have low friction because clay separates rock surfaces negating the joint roughness.
7. Geologic Character (Case 2) – Case 2 is for slopes where differential erosion or over-steepening occurs. Erosional features include over-steepened slopes, unsupported rock units above easily weathered rock, or exposed rocks on a slope. The structural conditions in Case 2 are divided into four groups based on existence and distribution of the erosion features in a slope. They range from few differential erosion features (Score = 3) to major erosion features (Score = 81). The rate of erosion directly relates to the rockfall potential. As erosion progresses, unsupported or over-steepened slope conditions worsen. A small difference in erosion rates (Score = 3) suggests that erosional features will take many years to develop. A moderate difference in erosion rates (Score = 9) suggests that erosional features will develop over a few years. A large difference in erosion rates (Score = 27) causes erosional features to develop annually. An extreme difference in erosion rates (Score = 81) suggests that slopes are not in equilibrium with the environment and that erosional features will develop rapidly.
8. Block Size or Quantity of Rockfall per Event – This category is evaluated with 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 block size, the largest block that is likely to fall is measured on a side. The length, in feet, is used as the exponent to which 3 is raised,

producing the category score. If a mass of blocks moves in rockfall, the quantity per event should be used. For quantity per event, the rockfall volume, in $(\text{feet})^3$, divided by 3 is used as the exponent to which 3 is raised, producing the category score.

9. Climate and Presence of Water on Slope – Freeze-thaw cycles and water contribute to weathering. Annual precipitation less than 20 inches is considered low precipitation, whereas more than 50 inches is considered high precipitation. The climate condition and water presence is divided in four categories: low precipitation and no freezing (Score = 3); moderate precipitation, short freezing, or intermittent water on slope (Score = 9); high precipitation, long periods of freezing, or continual water on slope (Score = 27); and high precipitation with long freezing periods, or continual water on slope with long freezing periods (Score = 81).
10. Rockfall History – This information represents the known rockfall activity. The maintenance cost at a site may be used as a substitute in areas where the rockfall record is not available. The rockfall history is grouped according to the number of rockfalls recorded. The few falls category (Score = 3) indicates that rockfalls have occurred several times, but are not a persistent problem. This category also is used if no rockfall history record is available. For occasional falls (Score = 9), rockfall occurs several times a year and during most storms. The many falls category (Score = 27) represents the condition in which rockfall occurs frequently during a certain season; however, it is not a significant problem during the rest of the year. The constant falls category (Score = 81) indicates areas where rockfalls occur frequently throughout the year.

In addition to rating the rockfall hazard, RHRS provides recommendation of remedial measures best suited for a particular site based on mitigation cost estimates. The hazard reduction measures vary from slope scaling to installing rockbolts, mesh, and shortcrete.

2.2 Oregon DOT-II (ODOT II)

Oregon DOT implemented a new system in 2001, which is intended for both landslide and rockfall applications. The initial idea was to merge the existing RHRS with a new landslide rating system. Instead, a new rating system was developed that can be applied to all unstable slopes, including rockfalls, landslides, debris flows or combinations thereof (ODOT 2001).

The new Oregon DOT slope rating system includes three groups of parameters: (1) hazard score; (2) maintenance benefit-cost factor; and (3) highway classification factor. Assessment of the hazard score is based on five categories (ODOT 2001):

1. Failure Hazard/ Speed Failure - This category is based on the speed of the slide or rockfall event and its ability to create an immediate hazard. All rockfalls and debris flows are rated in the high hazard category, because they are inherently fast-moving. Landslide and fill failure ratings are based on the history of previous slide events and the judgment of the rater. The high hazard sites are scored between 81 and 100, based on the percentage of the AASHTO sight distance available to drivers reaching the hazard site. The score is found by multiplying the percent sight distance by 0.247 and then subtracting the result from 108.91 with limits to the score of 81 for the minimum and 100 for the maximum.

2. Roadway Impact - This category determines how traffic will be affected after a major failure, based on the remaining width of the road. It is divided into two sections: landslides and rockfalls. Landslides and fill failures are scored based on the estimated roadway width remaining after slope failure and the effect on the traffic flow. Because rockfalls do not affect roadway width consistently, rockfalls are scored for their ditch effectiveness instead.
3. Annual Maintenance Frequency - This is the average number of events or failures per year at each site in the last 10 years. It reflects the average number of times a year maintenance crews respond to cleanups or hazardous conditions at a site. If maintenance frequency is less than once a year, the score is 50 times the annual frequency. When maintenance occurs more than once a year, the frequency is multiplied by 12.5 and then added to 37.5, but may not exceed a maximum score of 100.
4. Average Daily Traffic - The ADT is the average number of vehicles that pass through a site each day. The ADT is on a sliding scale from 0 to 100 points as traffic increases from zero to 96,000 or more cars per day.
5. Accident History – This category includes four divisions: (1) no accidents; (2) vehicle or property damage; (3) injury; and (4) fatality. A fatality receives a score of 100 due to the liability associated with such a severe consequence.

Each of the five hazard categories has a maximum score of 100 points; therefore, the highest possible hazard score for a site is 500 points (see Figure 2.1). Each category score is summed to obtain the total hazard score.

The next step in the system is to multiply the total score by two factors in order to provide a final ranking for the State Transportation Improvement Program (STIP). These factors are: (1) the maintenance benefit-cost factor, and (2) the highway classification factor. The maintenance benefit-cost ratio is the 20-year maintenance cost divided by the permanent repair cost. The highest factor of 1.5 is applied when maintenance over 20 years is twice what it would cost to fix the failure. A benefit-cost ratio below 0.5 likely would not receive funding for a permanent fix, since the repair cost would be more than twice of the maintenance cost. One of the shortcomings is that this system does not account for partial risk reduction. The highway classification factor accounts for route importance. Once these factors are applied, the new score is the final STIP score.

The last step in the STIP selection process is to account for the estimated repair costs and other non-scoring factors. These items include the following:

1. Delay cost or financial impact to the public, if lanes are closed
2. Lifeline priority route
3. Existence of culvert within the slide boundary
4. Environmental impacts, such as sediment being introduced into a stream
5. Impacts to adjacent structures or private properties
6. Interagency funding opportunities

Hazard Score

Failure Hazard	Very small or insignificant failures that do not affect the roadway (Not Scored)	**Low Hazard**: Slower slides with low potential for causing a road hazard. (9 Points)	**Medium Hazard**: Slides that have not moved suddenly in the past but have the potential to cause a road hazard. (27 Points)	**High hazard:** Rapid slides that have created road hazards in the past; and all debris flows and rockfalls (81-100 Points based on sight distance)

Roadway Impact	**Landslide**	Would only affect shoulder during major failure (3 Points)	Two-way-traffic would remain after a major failure (9 Points)	One-way traffic would remain after a major failure (27 Points)	Total closure in the event of major failure with 0-3 mile detour (54 Points)	Total closure in the event of major failure with 3-10 mile detour (70 Points)	Total closure in the event of major failure with 10-60 mile detour (85 Points)	Total closure in the event of major failure with >60 mile detour (100 Points)
	Rockfall	Rocks are completely contained in the ditch (3 Points)	Rocks fall onto the shoulder (9 Points)	Rocks enter the roadway (27 Points)	No ditch; all rocks enter roadway (81 Points)	Rocks occasionally fill all or part of a lane (100 Points)		

Annual Maintenance Frequency	Once every 5 years or less (0 Points)	Once every 4 years (13 Points)	Once every 3 years (17 Points)	Once every 2 years (25 Points)	Once every 1 to 2 years (38 Points)	Once a year (50 Points)	1 to 2 times a year (56 Points)
	2 times a year (63 Points)	2 to 3 times a year (69 Points)	3 times a year (75 Points)	3 to 4 times a year (81 Points)	4 times a year (88 Points)	4 to 5 times a year (94 Points)	5 times a year or more (100 Points)

Average Daily Traffic	0-499 (11 Points)	500-999 (22 Points)	1,000-2,999 (33 Points)	3,000-5,999 (44 Points)	6,000-11,999 (56 Points)	12,000-23,999 (67 Points)	24,000-47,999 (78 Points)	48,000-95,999 (89 Points)	96,000 and over (100 Points)

Accident History	No accidents (3 Points)	Vehicle or property damage (9 Points)	Injury (27 Points)	Fatality (100 Points)

Total possible: 500 points

Maintenance Benefit-Cost Factor

<u>20-Yr. Maintenance Cost</u> Repair Cost	Factor
> 0.0 - 0.2	0.5
≥ 0.2 - 0.4	0.75
≥ 0.4 - 0.6	1
≥ 0.6 - 0.8	1.06
≥ 0.8 -0.10	1.12
≥ 1.0 - 1.2	1.18
≥ 1.2 - 1.4	1.24
≥ 1.4 - 1.6	1.3
≥ 1.6 - 1.8	1.36
≥ 1.8 - 2.0	1.42
≥ 2.0	1.5

Highway Classification Factor

District	Regional	Statewide	Interstate
1	1.05	1.1	1.2

Figure 2. Oregon DOT II Unstable Slopes Rating System (taken from ODOT 2001)

2.3 Ohio DOT (OHDOT)

The Office of Geotechnical Engineering (OGE) within the Ohio Department of Transportation uses the Geological Hazard Management System (GHMS) to manage geological hazards data and activities related to planning, design, construction, and maintenance. The geological hazards include abandoned underground mines, karsts, and shoreline erosion. In 2007, a landslide hazard rating system was developed for the Ohio DOT and incorporated into the GHMS (Liang 2007). This system evaluates six landslide risk factors that potentially impact the safety and operation of a roadway and adjacent highway structures. Each of the risk factors is rated using a scoring system similar to Oregon DOT-I. The numerical scores of 3, 9, 27 and 81 represent the increasing hazard of each factor (see Table 2.3). The risk factors include:

1. Movement location and impact on roadway – The location and impact of slope movement are divided into two subcategories: (1) impact on roadway and (2) impact beyond right-of-way.
2. Hazard to traveling public – This factor is assessed based on the slope movement rate or the amount of total movement of a slope in a single event. Since the rate of slope movement may not be available at the time of the site survey, an alternative approach involves estimating the total movement in terms of vertical and horizontal displacement as seen in visible cracks and dips in the roadway or structure.
3. Percent decision sight distance - The percent decision sight distance is a comparison between the actual sight distance and the standard sight distance recommended by AASHTO. The sight distance is the distance along highway at which an object 6-inches high is continuously visible to a driver at a height of 3.5 feet above the road surface. The shortest distance in which this object in no longer visible is the actual sight distance. The investigator needs to consider both traffic directions.
4. Average daily traffic - Average daily traffic (ADT) is an average number of vehicles passing through a section of the roadway per day. ADT indicates the importance of the roadway. Closing the road for remediation may affect regional economy. Therefore, remediation of landslides in areas with high ADT should be considered priorities, and warrant higher scores.
5. Accident history - The accident history is important in the landslide hazard assessment. If a slope site has records of injury or fatality due to slope failure, the site should receive a high score in this category.
6. Maintenance – Maintenance frequency reflects the intensity of the past maintenance activity at a slope site. A site having a high maintenance frequency indicates that the slope movement at the site is persistent. As maintenance frequency increases, a sense of urgency to mitigate the problem heightens. If the maintenance frequency is not known, the rater should determine the appropriate maintenance response.

The final hazard score of a landslide site is determined by adding all six scores. A total score greater than 250 is considered to represent high hazard potential, a score between 150 and 250 represents moderate hazard, and a score less than 150 is low hazard.

Table 2. Ohio Landslide Hazard Rating System (taken from Liang 2007)

CATEGORY		RATING CRITERIA AND SCORE			
		3	9	27	81
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or on slope with a high potential to affect roadway or structure
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way (A)	On slope with moderate potential to impact area beyond right of way (B)	On slope with a high potential to impact area beyond right of way (C)	On slope with high potential to impact structure beyond right of way (D)
Hazard to travelling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/ year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches
	Evidence of displacement in roadway	Visible crack or dip no vertical drop (E)	≤1-inch of displacement (F)	1 to 3-inches of displacement (G)	≥3-inches of displacement (H)
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/year)	Continuous thoughout year (> 3 times/year)
	Maintenance response	No Response (I)	Requires observation with periodic maintenance (J)	Requires routine maintenance response to preserve roadway (K)	Requires immediate response for safe travel or to protect adjacent structure (L)
ADT		<2000 (M)	2001-5000 (N)	5001-15000 (O)	>15001 (P)
%Decision Sight Distance (DSD)		≥ 90 (Q)	89-50 (R)	49-35 (S)	< 34 (T)
Accident History		No accident (U)	Vehicle or property damage (V)	Injury (W)	Fatality (X)

Establishing an unstable slope using this system involves several levels of the Ohio DOT and county personnel (see Figure A.2). Reporting of a potential landslide site is initiated by completing the Landslide Observation Report by a highway maintenance/construction worker or a crewmember from a County Office. Once the county/transportation manager (CM/TM) receives the Landslide Observation Report, the manager makes a trip to the reported landslide site to verify the submitted information. If he/she determines that it is not landslide-related, there is no follow-up activity. The Landslide Observation Report is kept for future reference. If CM/TM determines that it is a landslide, then the Landslide Field Reconnaissance Form, Part A is completed. The CM/TM determines the significance of the landslide site using the *rated* and *non-rated* criteria provided in the form. If it is classified as *non-rated*, CM/TM will set up a schedule for revisit. If it is classified as *rated*, CM/TM completes the Part B form, which requires a compilation of landslide site history and traffic data, such as maintenance frequency and cost, traffic counts, speed limit, and accident record. Once OGE receives notification from CM/TM, the OGE staff will prepare a field team for a site visit. OGE will then perform a detailed site assessment using the landslide hazard rating matrix to complete the Landslide Field Reconnaissance Form, Part C.

2.4 New York DOT (NYSDOT)

In 1988, the Geotechnical Engineering Bureau within the New York DOT adopted an unstable slope program to identify and evaluate a total of 1,741 sites. The program uses an initial rating system based on a procedure originally developed for the Federal Highway Administration (FHWA) by Duncan C. Wyllie of Golder Associates (NYSDOT 2007). Since the program's initial adoption, new sites were added to the inventory, and revisions were made to the system in 1993. The revised system includes the following improvements:

1. Three components of a possible rockfall-vehicle accident (i.e. geologic, section, and human exposure factors) are isolated as independent factors.
2. The amount of risk associated with a falling rock hitting a vehicle, as well as the risk of a vehicle hitting a fallen rock, is more objectively addressed.
3. The system considers both the risk posed by an existing rock slope, and the level of risk remaining after remediation.

This rating system establishes relationships among the following three factors used to assess comparative risks of accidents caused by rockfalls:

1. Geologic Factor (GF): This is the risk of rock(s) falling, based on the slope's specific geologic and physical characteristics. The numerical value for GF is the sum of the associated rating categories divided by 10. The division by 10 is solely to reduce its numerical value. Each category is scored on a scale ranging from 1 to 81, with 1 the lowest risk and 81 the highest (see Table 2.4).
2. Section Factor (SF): This factor represents the relative risk of fallen rocks reaching the highway's travel lanes. It is related to ditch configurations and slope offset from the pavement edge (or shoulder edge where one exists). SF is the ratio of the required Ritchie criteria to actual dimensions. It ranges from 1 or less in the best circumstances, to about 11 in the worst. The SF can be calculated using the following equation:

Table 2. Rating for Geologic Factor (taken from NYSDOT 2007)

	Rating	1	3	9	27	81
1A	GEOLOGY (Crystalline)	Massive, no fractures dipping out of slope	Discontinuous fractures, random orientation	Fractures that form wedges	Discontinuous fractures dipping out of slope	Continuous fractures dipping out of slope
1B	GEOLOGY (Sedimentary)	Horizontal to slightly dipping	Raveling, occasional small blocks	Small overhangs or columns, numerous small blocks	Overhangs, some large unstable blocks, high columns	Bedding or joints dipping out of slope, over-steepened cut face
2	BLOCK SIZE	6 in. (150 mm)	6 in. to 12 in. (150 mm to 300mm)	1 ft to 2 ft (0.3 m to 0.6 m)	2 ft to 5 ft (0.6 m to 1.5 m)	5 ft or more (1.5 m or more)
3	ROCK FRICTION	Rough, irregular	Undulating	Planar	Smooth, slickensided	Clay, gouge-faulted
4	WATER/ICE	Dry	Some seepage	Moderate seepage	High seepage/ brush	High seepage with long backslope / brush
5	ROCKFALL	No falls	Occasional minor falls	Occasional falls	Regular falls	Major falls/slides
6	BACKSLOPE ABOVE CUT	Flat to gentle slope (up to 15°)	Moderate slope (15° - 25°)	Steep slope (25° - 35°)	Very steep slope (> 35°) or steep slope (25° - 35°) with boulders	Very steep slope (>35°) with boulders

$$SF = (DR+WR) / (DA + WA)$$

where DR is the idealized ditch depth, WR is the idealized ditch width, DA is the actual ditch depth, and WA is the actual distance between toe and pavement edge/shoulder.

3. Human Exposure Factor (HEF): This factor evaluates the relative risk of a traffic accident occurring if a rockfall occurs and rock comes to rest on the roadway. A vehicle may be threatened by one of two conditions: 1) a falling rock hits a vehicle (i.e. active condition, F_a); or 2) a vehicle hits a rock on the roadway (i.e., passive condition, F_p). The risk value of each condition is calculated based on traffic volume and stopping sight distance. For example, F_a is calculated as:

$$F_a = AADT \times [(L + SSD)/(V \times 24{,}000)]$$

where AADT is the average annual daily traffic, L is the length of rockfall zone, SSD is the stopping sight distance, DSD is the decision sight distance, and V is the travel speed. F_p is calculated as:

$$F_p = \log_{10} (AADT) \times \log_{10} (L)[a/(SSD - a)]$$

where a is the maximum value of either (SSD - DSD) or 0. Finally, the HEF value is defined as the sum of the active and passive risk values divided by 3 [i.e. HEF = (F_a + F_a)/3].

Total relative risk of an accident occurring at a rock slope site can now be established. If SF is 1 or less, the Total Relative Risk (TRR) is set at 1. Otherwise, it is equal to the product of the three factors:

$$\text{Total Relative Risk (TRR)} = \text{GF x SF x HEF}$$

The system allows DOT officials to evaluate the cost-benefits for different slope treatments. Risk reduction is the difference between the calculated TRRs before and after slope remediation.

2.5 Utah DOT (UDOT)

The Utah Department of Transportation's (UDOT) rockfall rating system involves two phases. Phase I is a rockfall hazards inventory and Phase II is the subsequent rockfall hazards rating. UDOT's initial unstable slope inventory was completed in 2001. The rockfall hazard rating system (RHRS) developed by ODOT was adopted as the Phase I system, to identify slopes that warranted further investigation under Phase II. The RHRS classified rockfall sites into three broad, manageably sized categories labeled as A, B, or C (Pack and Boie 2002). UDOT assessed a total of 1,099 sites, which were divided into 479 A sites (representing 83.6 road miles), 569 B sites (representing 92.3 road miles), and 51 C sites (representing 4.7 road miles). The A and B sites were further subdivided to differentiate the slope sites with moderate risk. For example, the B-class slopes that had a clearly moderate risk were rated as B+, and the A-class slopes that were moderate rather than high risk were rated as A-.

The database for the Phase II evaluation was constructed from the A, B, and some C sites, which included some basic site descriptions, locations, and photographs. Inclusion of a few C sites was simply to compare the rating results with the A-rated and B-rated sites. The inventory provided an overview of the magnitude of the rockfall problem across the state of Utah. This database was used to identify rockfall sections throughout the highway system for mitigation during a five-year Utah Statewide Transportation Improvement Program (STIP).

UDOT's initial plan for Phase II was to carry out a detailed rockfall hazard study only for the 479 A sites. Additional B sites would be investigated as the future budget allowed. However, the final decision was to include the B+ sites so that their true ranking relative to the A sites could be assessed (Pack, et al. 2006).

During Phase II, the A and B+ sites were evaluated over a two-year period using the previously developed Oregon DOT I and II and NYSDOT unstable slope hazard rating systems. The comparative study of the three rating systems was intended to select the suitable parameters for development of the UDOT rating system. Phase II also included the implementation of a GIS database, linking the spatial data to the Utah highway grid.

Although the three rating systems used similar data to evaluate site risk, the systems varied greatly in some instances as to what constitutes a hazardous site. After a thorough review of the rating results, the UDOT Technical Advisory Committee decided that the NYSDOT system more realistically analyzed the "risk" associated with rockfall sites in Utah. Additionally, UDOT revised the Geologic Factor (GF) of the NYSDOT system by doubling the weight in rockfall frequency and block-size parameters. The revised GF is calculated as:

GF = Geology + 2 * Block_Size + Rock_Friction + Water + 2* History + Backslope

One additional change, though minor, was the term used to describe geology. The term "sedimentary" was replaced by the term "layered" in the UDOT system to eliminate the lithologic connotation. The Total Relative Risk (TRR) is calculated as discussed in Section 2.4.

2.6 Washington DOT (WSDOT)

The development of the Washington State Department of Transportation (WSDOT) Unstable Slope Management System (USMS) began in 1993, using a new approach for the state highway construction program. This new approach involved prioritizing and programming projects based on the extent to which they addressed road deficiencies along the highway system (Lowell and Morin 2000). One of the program objectives is the proactive stabilization of known unstable slopes.

The first major work in developing the USMS was to populate a list of known unstable slopes along the state highway system. WSDOT divided the task among six regional maintenance divisions. Pertinent information collected at this stage included the location of the slope and its position relative to centerline, types of slope instability, frequency of failure, and estimated annual maintenance costs. Early in the inventory process, three subjective categories were used to identify the failure potential of unstable slopes: Category A (high potential), Category B (moderate potential), and Category C (low potential). Since the majority of the unstable slopes in the inventory were rated using a matrix-based rating system, this interim subjective categorization was discontinued.

The matrix-based rating system includes eleven risk categories that prioritize individual slope within the inventory (see Figure 2.2). A unique feature of the WSDOT's system is that it includes and consistently rates rock slope instabilities, landslides, and settlement and erosion problems. The total score can range between a low of 33 and a high of 891. A higher score generally correlates to a higher level of risk to the highway. However, the USMS is not a predictive model. To ensure the highest return on maintenance expenditure, the WSDOT's system prioritizes the slopes for evaluation based on: (1) highway functional class, (2) USMS numerical rating, and (3) average daily traffic (ADT). Slopes along interstate facilities and principal arterials are prioritized for remediation, followed by those along lower volume roads. Within the same highway functional class, the slopes are ranked in descending numerical order, with the highest-risk slopes prioritized for remediation (Lowell and Morin 2000). Because of limited budget, mitigation of unstable slopes involves a cost-benefit analysis. The analysis divides the anticipated cost of traffic impacts resulting from a slope failure and the maintenance costs over a 20-year period by the permanent repair cost. Only those slopes with cost-benefit ratios above 1.0 are considered for mitigation (Lowell et al. 2002?). The eleven risk categories include (MacDonald 2006):

1. Problem Type: *Soil*: These unstable slope conditions deal exclusively with soil or soil-like instabilities. They include slope erosion, settlement, landslides, and debris flows, and are rated based on the potential speed of failure. *Rock*: These unstable slope conditions deal exclusively with rockfall. This category evaluates the roadway catchment

Unstable Slope Rating Form

WSDOT, Geotechnical Services, Unstable Slope Management Unit

REGION	
SR	
BEG MP	
END MP	
Side L for Left R for Right or L,R	
Functional Class	

RATED BY (initial)	
DATE	

SPEED, posted (mph)	
SIGHT DISTANCE, estimated (ft)	
DECISION SIGHT DISTANCE, (ft)	

RATING CRITERIA *(place an "X" to select a criterion from each category*

CATEGORY		3	9	27	81	POINTS
PROBLEM TYPE	SOIL OR	CUT or FILL SLOPE EROSION	SETTLEMENT or PIPING	SLOW MOVING LANDSLIDES	RAPID LANDSLIDES or DEBRIS FLOWS	
	ROCK Rockfall/ Catchment	MINOR / GOOD	MODERATE / FAIR	MAJOR / LIMITED	MAJOR / NONE	
ADT avg daily traffic	fill in value	<5K	5-20K	20-40K	>40K	
Truck ADT	fill in value					
PDSD % of decision sight distance		ADEQUATE 100%+	MODERATE 80-99%	LIMITED 60-79%	VERY LIMITED <60%	
IMPACT OF FAILURE ON ROADWAY		< 50'	50' - 200'	200' - 500'	> 500'	
	fill in value (ft)					
ROADWAY IMPEDENCE		SHOULDER ONLY	½ Roadway	¾ Roadway	FULL roadway	
AVERAGE VEHICLE RISK		<25%	25-50%	50-75%	>75%	
PAVEMENT DAMAGE		MINOR Not Noticeable	MODERATE Driver Must Slow	SEVERE Driver Must Stop	EXTREME Not Traversible	
FAILURE FREQUENCY		0/5 YR	1/5 YR	1/YR	1+/YR	
MAINTENANCE COSTS ($/yr)		< 5000	5-10K	10-50K	>50K	
ECONOMIC FACTORS detours		NO Detour Required	SHORT Detour, <3mi	LONG Detoura Detours, >3mi	SOLE ACCESS No Detour	
ACCIDENTS (in last 10 years)	fill in value	0 TO 1	2 TO 3	4 TO 5	> 5	
TOTAL POINTS						

Figure 2. WSDOT Unstable Slope Rating Form (taken from MacDonald 2006)

available to contain and prevent falling rock from entering the roadway. This category also subjectively evaluates the size of the events in terms of rock size and volume. Minor rockfall is less than one foot in diameter and less than three cubic yards in volume;

moderate rockfall is between one to two feet in diameter and three to six cubic yards in volume; and major rockfall is greater than two feet in diameter and greater than six cubic yards in volume.

2. Average Daily Traffic: This category rates the current Average Daily Traffic along the section of highway where the unstable slope is located.
3. Percentage Decision Sight Distance (PDSD): The decision sight distance is the minimum distance in feet required for a driver to detect a hazard, make an instantaneous decision, and take a corrective action. The actual DSD is measured along the edge of pavement in the direction of oncoming traffic. It is the distance from the edge of a hazard zone to where a 6 in. object disappears when viewing the road at a height of 3.5 ft above the ground. The Percent Decision Sight Distance (PDSD) is the ratio as a percentage of the actual sight distance and the decision sight distance.
4. Impact of Failure on Roadway: This category summaries the actual failure length as measured in the field of the unstable area along the roadway.
5. Roadway Impedance: This category rates the impedance to traffic due to the failure of an unstable slope. It is based on the width of impacted roadway.
6. Average Vehicle Risk (AVR): AVR measures the percentage of time that a vehicle will be present in an unstable slope area. The AVR number can be greater than 100%, which means that there is more than one vehicle present within the unstable area at any given time.
7. Pavement Damage: This category evaluates the severity of the potential damage to the roadway surface due to the failure of an unstable slope. The rating is based on the traversability of the unstable area by a motorist traveling at the posted speed limit.
8. Failure Frequency: This category summarizes the failure frequency of the unstable slope.
9. Annual Maintenance Cost: This summarizes the annual maintenance cost related to an unstable slope.
10. Accidents in the Last 10 Years: This category summarizes the number of accidents associated with the unstable slope.
11. Economic Factor: This category rates the potential economic impact of a roadway closure due to the failure of an unstable slope. It is based on the availability and length of a detour around the failure area. Several factors, such as detour conditions, traffic volume, and potential traffic flow, must be considered when determining the suitability of a detour route.

2.7 Tennessee DOT (TDOT)

The Tennessee Department of Transportation (TDOT) developed a rockfall hazard rating system (TRHRS) in 2000. The preliminary rating process, using the standard NHI Rockfall Hazard Rating System (RHRS), identified about 80 slopes from five counties that required a detailed rating. The Tennessee RHRS detailed rating system is similar to the NHI RHRS. However, three categories were modified to provide better characterization of the critical features along the

Tennessee road system, and to improve repeatability and consistency among raters (Mauldon et al. 2007). The TRHRS requires two steps to rate the potential rockfall hazards on interstate, primary, and secondary state highways:

1. Preliminary rating and inventory of rock slopes: Rock slopes are classified initially as A (high hazard), B (moderate hazard), or C (low hazard). For A and B slopes, the location is entered into a geographic database, basic data pertaining to the slope is collected, and the slope is photographed. Low hazard slopes are not recorded.
2. Detailed rating of high hazard (A) slopes: Information is gathered on the rock slopes using the TRHRS. Identified rockfall sites are prioritized based on the hazard scores.

Like other DOT's rating systems, each factor in the TRHRS is assigned a score that increases exponentially from 3 to 81 with the degree of hazard, and the scores of all categories are summed to yield an overall score. The detailed rating system has the following categories (see Figure 2.3):

1. Slope Height: This can be determined two ways: (1) by visual estimation, or (2) by measurement. Estimation of height should be done to the nearest ten feet.
2. Ditch Effectiveness: The category rates the slope and launching features and the design catchment width.
3. Average Vehicle Risk (AVR): The AVR is determined based on the average daily traffic (ADT), the measured slope length, and the posted speed limit.
4. Roadway Width: This is measured from pavement edge to pavement edge perpendicular to the roadway centerline. If the width varies along a road section, the narrowest width is recorded.
5. Percent Decision Site Distance (PDSD): The Percent Decision Sight Distance (PDSD) is the ratio as a percentage of the actual sight distance and the decision sight distance.
6. Geologic Characteristics: The TRHRS characterizes all potential failure modes at a slope site, scores each failure mode, and sums the scores rather than scoring only the mode with the greatest potential for failure. Structurally controlled failure modes are plane, wedge, and toppling failure, while the weathering controlled failure modes are differential weathering and raveling. Characteristics pertinent to all failure modes are the relative *abundance* of the failure zone as a percentage of the total cut surface area, and *block size,* which is the longest dimension of the blocks. Characteristics unique to plane and wedge failure are *steepness* of the failure surface and the *micro-* and *macro-friction profiles* of the failure surface. The a*mount of relief* is a characteristic unique to differential weathering, and *block shape* is unique to raveling.
7. Presence of Water on Slope: This category scores the amount of water and type of flow on a slope face. The score varies from none (Score = 3) to gushing (Score = 81).
8. Rockfall History: Maintenance records are the best source of information about rockfall history. However, if records are not available, rockfall history is best assessed by the amount of material in the catchment, number of impact marks in the road caused by falling rocks, and the presence of rocks in the road.

TDOT RHRS FIELD SHEET v 1.1

I. TRIMS/Preliminary Data

Date			
File No.			
County No.		Rater	
Route No.		Speed Limit	
Beg. L.M.		District	
Ref C/L		ADT	
County Region		Latitude Longitude	

II. Site and Roadway Geometry

1. Slope Height (ft)

Estimated		Ft.	
alpha (a)		beta (b)	
width (x)	(Ft)	Instrument height (H.I.)	(Ft)

Slope Height $= \frac{\sin a * \sin b * X}{\sin(a-b)} + H.I.$

2. Average Vehicle Risk (AVR)

$$AVR = \frac{ADT\left(\frac{cars}{day}\right) * (Rock\ Slope\ Lenght \div 5280)}{((24\ hpd) * Speed\ Limit\ (mph))}$$

Slope Length ft Speed Limit ft AVR= %

3. % Decision Site Distance (%DSD)

Choose one:	Adequate	Moderate	Limited	Very Limited
OR	3	9	27	81

Calculate $\frac{}{(Observed\ DSD)} \div \frac{}{(AASHTO\ DSD)} \times 100 =$ %

4. Road Width (ft)

1	Slope Height	
2.	AVR	
3.	%DSD	
4.	Road Width	
5.	Ditch Effectiveness	
6.	Rockfall History	
7.	Water	
8.	Geologic Character	

SCORING

Total Score ______

5. Ditch Effectiveness

Design Catchment Width (feet)

Slope Height (ft)	Recommended width for vertical slope	Recommended width for non-vertical slope
0-40	18	18
40-50	18	24
50-60	24	30
60-70	28	34
70-80	32	38
80-100	36	42
100-125	36	42
125-175	40	48
>175	52	60

Effective catchment width (ft)

Launching Features (yes or no)

6:1 Catchment shape? (yes or no)

Percentage of Design Catchment Width from Table	>90	70-90	50-70	<50
Score with 6:1 or greater catchment slope	3	9	27	81
Score w/ Poor Catchment or Launch Features	9	27	81	81
Score w/ Poor Catchment and Launch Features	27	81	81	81

6. Rockfall History

Benchmark	Frequency	Field Judgment	Score
Few	1 or less per year	No impact marks in the road, no rocks in the road, few rocks in ditch	3
Several	2 per year	No impact marks in the road, no rocks in the road, many rocks in the ditch	9
Many	3 -4 per year	Few impact marks or few rocks in the road	27
Constant	5 or more per year	Many impact marks and/or many rocks in the road	81

III. Geologic Characteristics (circle all that apply; modes are additive)

	Planar				Wedge			
Abundance	<10 %	10-20%	20-30%	>30%	<10 %	10-20%	20-30%	>30%
Score	3	9	27	81	3	9	27	81
Block size	<1 ft	1-3 ft	3-6 ft	>6 ft	<1 ft	1-3 ft	3-6 ft	>6 ft
Score	3	9	27	81	3	9	27	81
Steepness (degrees)	0-20	20-40	40-60	>60	0-20	20-40	40-60	>60
Score	2	5	14	41	2	5	14	41
Friction (micro/macro)	rough/ Smooth/ undulating	smooth/ undulating	rough/ planar		rough/ Smooth/ undulating	smooth/ undulating	rough/ planar	planar
score	2	5	14	41	2	5	14	41

8. Geology Score = ______

	Topple/B. Release				Differential Weathering					Raveling			
Abundance	<10 %	10-20%	20-30%	>30%	<10 %	10-20%	20-30%	>30%	Abundance	<10 %	10-20%	20-30%	>30%
Score	5	14	41	122	3	9	27	81		3	9	27	81
Block size	<1 ft	1-3 ft	3-6 ft	>6 ft	<1 ft	1-3 ft	3-6 ft	>6 ft	Block size	<1 ft	1-3 ft	3-6 ft	>6 ft
Score	5	14	41	122	3	9	27	81		3	9	27	81
Relief					<1 ft	1-3 ft	3-6 ft	>6 ft	Block Shape	Tabular	blocky	round	
Score					3	9	27	81		3	9	27	

7. Presence of Water on Slope

(choose one)

None	Seeping	Flowing	Gushing
3	9	27	81

Notes:

Figure 2. Tennessee DOT RHRS survey sheet (taken from Mauldon et al. 2007)

2.8 Missouri DOT (MODOT)

The Missouri Department of Transportation (MODOT) developed its rock fall hazard rating system (MORFH RS) in 2004. In MORFH RS, risk and consequence factors have equal weight and are isolated from each other. The rating system can be used to cost effectively determine the need and priority of remediation, and help facilitate the design of maintenance on rock cuts (Maerz et al. 2005). Similar to most other unstable slope management systems, MORFH RS utilizes two steps to populate and prioritize potential problematic slopes:

1. Identification of the most potentially problematic rock cuts using mobile digital video logging;

2. Evaluation of parameters for each identified slope. Parameters include: slope height, slope angle, ditch width, ditch depth, shoulder width, block size, ditch capacity, expected rock fall quantity, weathering, face irregularities, face looseness, strength of rock face, water on the face, design sight distance, average daily traffic, number of lanes, average vehicle risk; and conditional parameters, such as adversely oriented discontinuities, karst features, ditch capacity exceedence, and the effect of bad benches.

Figure 2.4 is an example of the MORFH RS survey sheet. The MORFH RS includes nine risk factors, ten consequence factors, three adjustment factors, and one internally calculated value. Some of the factors involving dimensional measurements can be estimated using computer-scaled video images of rock cuts in the office. However, descriptive factors, such as weathering, rock strength, face irregularities, and looseness require field evaluation. For each parameter, the input value is either an actual measurement or one of an assigned class value between 0 and 4 in increments of 0.5.

These factors are organized into "risk of failure" and "consequence of failure" categories. The risk rating is plotted against the consequence rating, and a potential slope is classified based on these two values. Although the assessment method of MORFH RS is different from the unstable slope management programs used by other state DOTs, the risk and consequence classifications are comparable to the hazard and risk categories used.

2.9 British Columbia Ministry of Transportation (MoT), Canada

In 2000, the BC Ministry of Transportation (MoT) adopted a new Rock Slope Stability Policy, which provided the framework for a rock slope stabilization program. The policy outlined the adoption of the Rockfall Hazard Rating System (RHRS) developed by the Oregon DOT. Before implementing the RHRS, the imperial units and AASHTO standards were converted to metric units and the Transportation of Canada (TAC) standards. The linear referencing system for locating roadway sections also was changed (Gerraghty 2006).

Significant changes made to the RHRS by the BC MoT are:

1. The slope height is adjusted from 10 m to 40 m with scoring values from 3 to 81.
2. A "continuous joint" in the Structural Condition in Case 1 is changed from 10 feet to 10 meters.
3. The freezing period in the Climatologic Effect category is modified. Two sets of guidelines divide the freezing period into "none," "short," and "long." The freezing period is defined using degree-days.
4. Slopes are separated into either rock or soil slopes, as defined by the primary source of material.
5. Only certain discrete values are used in some of the rating categories. These categories include block size and/or quantity of rockfall per event and rockfall history.
6. Remediated roadway sections are defined as those with some visible rockfall mitigation other than a ditch. Remedial works are considered effective unless observations from highway level identify damage. The effectiveness of the installation is reduced based on the level of damage observed.

A	Site No.		B	Latitude			
C	Highway		D	Longitude			
E	Mile Reference		F	Elevation			
G	Bench	Yes	No	If yes look at the faces above the bench			
1	Faces above bench	SCORE	12	6	0		
		Weathering	High	Low	Fresh		
		Face irregularity	High	Moderate	Smooth		
		Face Looseness	Large	Moderate	No		
		Bench width	Narrow<5ft	Moderate 15 ft	Wide>30 ft		
		Rock on the bench	Large amount	Moderate	No		
		Slope of the bench	Back slope	Horizontal	Toward road		
		Total Score:		If less than 36 then the bench is bad			
	Bench is	Good	Bad	If bad	Overall Slope^		
2	Slope Height	Ft		3	Slope angle		
4	Rock fall Instability	4 C Unstable	3 Unstable	2 Partially Stable	1 Stable	0 Completely Stable	
5	Weathering	4 High	3 Moderate	2 Low	1 Slightly	0 Fresh	
6	Strength factor (for the weakest zone)	4 Very Strong	3 Strong	2 Moderate	1 Weak	0 Very Weak	
7	Face Irregularities	4 Very High	3 High	2 Moderate	1 Slightly	0 Smooth	
8	Face Looseness	4 Very High	3 High	2 Moderate	1 Few	0 No	
9	Block size	Average discontinuity spacing			ft		
10	Water on Slope	0 Dry	1 Damp	2 Wet	3 Dripping	4 Flowing	
11	Ditch Width	Ft	11’	Ditch depth	Ft		
12	Ditch Volume	CU ft/ft	13	Shoulder Width	Ft		
14	Number of Lanes			ADT	Car/day		
16	Expected RFQ.	Area of the face		Depth of loose materials			
17	AVR	Speed Limit =	m/hr	Rock Cut Length=	Ft		
18	DSD	3 Very Limited	2 Limited	1 Moderate	0 Adequate		
19	Adjust. Factor	Discontinuity adversity		No <20	Fair 20-45	Unfavorable 45-65	Very Unfavorable >65
20	Adjust. Factor	Karst effect	4	3	2	1	0
		Width	150 ft	100 ft	50 ft	Carbonates	Non-Carbonates
		Materials	Boulders/cobbles in weak cement				
21	Ditch Shape If bad bench Or slope <90°	3 Flat 0°	2 Slight back slope 1V : 8H 7°	1 Moderate back slope 1V : 6H 9°	0 Large back slope 1V : 4H 14°		

Figure 2. MORFH RS survey sheet (taken from Maerz et al. 2005)

7. The cost estimation for rockfall mitigation methodology includes three phases: (1) a conceptual cost estimate; (2) a preliminary cost estimate; and (3) a detailed cost estimate. The purpose of this three-stage approach is to expedite the collection of cost information. The conceptual cost estimate (CCE) for slope remediation is based on the area of slope face to be stabilized. The preliminary cost estimate (PCE) requires quantities for each type of mitigation technique and the unit rates. The detailed cost estimate (DCE) is based on the accurate determination of quantities developed from detailed engineering assessment along with unit rates.

In 2004, the BC MoT revised the RHRS into a more risk-based system. Instead of using equal weight for all ten category ratings, the revision reorganized the ten categories into three major risk components. The hazard component includes three RHRS categories: (1) rockfall history, (2) climate, and (3) geologic character (Cases 1 and 2). The vulnerability component includes ditch effectiveness. The consequence component with active (i.e., rock hitting vehicle) and passive (i.e., vehicle hitting rock) scenarios includes: (1) AVR, (2) road width, (3) block size, (4) site distance, and (5) slope height. Each of the ten categories has an individual scaling factor. The calculation is done by multiplying each of the category ratings by a scaling factor. The scaled category scores then are multiplied together to obtain a sub-total for each risk component. The sub-total risk component scores are multiplied together to get the total risk score for each consequence scenario. The overall Total Risk Score is the sum of total risk scores for both active and passive consequences with a multiplier of 100,000. A higher Total Risk Score represents an increased risk level.

2.10 Summary

We reviewed nine unstable slope management programs. Most of the programs involve a two-stage implementation process, with preliminary and detailed evaluations. During the preliminary stage, quick reviews of the potential and failed slopes populate the database. In the detailed stage, typically a matrix-based rating system is used to evaluate the unstable slopes with high failure potential. However, there is no universal approach for the detailed evaluation. Among almost three dozen parameters used in the reviewed programs (see Table 2.5), only AADT is used directly or indirectly by all programs. The next most-cited parameters are the Average Vehicle Risk (including the Human Exposure Factor) and Percent Decision Sight Distance.

Prioritization of unstable slopes is based on the final rating score in the detailed review stage. All programs use the scoring system proposed by Pierson et al. (1990). There are two approaches in deriving the final rating score by either summing all individual category scores or by multiplying the individual category scores. Each, in its own way, has achieved the goal set by the state DOT administration. As we develop the unstable slope management program for the AKDOT&PF, we must keep in mind certain deficiencies in some of the reviewed programs. For example, none of them address the problems associated with slopes in permafrost. Only Ohio's DOT method includes instabilities in rock slopes, soil slopes, and fill. Table 2.6 is a list of the pros and cons of each of the reviewed unstable slope programs.

Table 2. Summary of parameters used in the reviewed unstable slope management systems

Parameters	ODOT I	ODOT II	OHDOT	NYSDOT	UDOT	WSDOT	TDOT	MODOT	BCMoT
AADT	x	x	x	x	x	x	x	x	x
Accident History		x	x			x			
Annual Maintenance Frequency		x							
Average Vehicle Risk/HEF factor	x		x	x	x	x	x	x	x
Annual Maintenance Cost		x	x						
Backslope above Cut				x	x			x	
Benefit-Cost Ratio		x	x			x			x
Block Size/Volume	x			x	x		x	x	x
Detour Distance/Time			x			x			
Differential Erosion	x			x	x		x		x
Discontinuity Length	x								x
Discontinuity Orientation	x						x	x	x
Discontinuity Roughness	x			x	x		x	x	x
Discontinuity Weathering								x	
Ditch Dimensions	x			x	x		x	x	x
Ditch Effectiveness	x	x		x	x		x	x	x
Expect Damages/Fatalities			x			x			
Failure Zone length	x		x	x	x	x	x	x	
Freezing Period/Freeze-Thaw Cycle	x								x
Future Impact			x			x			
Highway Classification		x				x			
Impact to Road Structure		x	x			x			
Instability related to Rock	x	x		x	x	x		x	x
Instability related to Soil		x				x			
Instability related to Fill		x							
%Decision Sight Distance	x		x	x	x	x	x	x	x
Rate of Movement		x	x						
Roadway Width	x						x		x
Rockfall/Slide Frequency		x	x						
Rockfall/Slide History	x						x		x
Slope Height	x						x	x	x
Slope Angle			x	x	x	x		x	
Traffic Speed	x		x			x			x
Vertical and Horizontal Displacement			x						
Water on Surface	x			x	x	x	x	x	x

Table 2. Summary of pros and cons of unstable slope hazard systems

Unstable Slope Program	Pros	Cons
ODOT I	+ Strong hazard rating system	- Weak risk component - Lacking asset management - Does not include soil slopes, fill failures, or frozen ground
ODOT II	+ Includes asset management + Uses highway function class	- Weak hazard rating - Does not include soil slopes, fill failures, or frozen ground
OHDOT	+ Includes rock slopes, soil slopes, and embankments	- Complex review procedures - Does not include frozen ground
NYSDOT	+ Includes risk assessment	- Heavily weights ditch effectiveness - Does not include soil slopes, fill failures, or frozen ground
UDOT	+ Includes risk assessment, with adjustments for geologic factor	- Heavily weights ditch effectiveness - Does not include soil slopes, fill failures, or frozen ground
WSDOT	+ Good risk and asset management program	- Weak hazard rating - Does not include fill failures or frozen ground
TDOT	+ Balanced hazard and risk rating	- Lacking asset management - Does not include soil slopes, fill failures, or frozen ground
MODOT	+ Balanced hazard and risk rating + Unique graphic relationship between risk and consequence	- Lacking asset management - Does not include soil slopes, fill failures, or frozen ground
BC MoT	+ Strong hazard rating system + Scaling factors for each category are not equal + Includes cost estimates	- Scaling factors increase low hazard and low risk potential - Does not include soil slopes, fill failures, or frozen ground

CHAPTER 3 – DEVELOPMENT OF AKDOT&PF UNSTABLE SLOPE MANAGEMENT PROGRAM

AKDOT&PF has been considering establishing a proactive unstable slope management approach in order to address public safety issues, while making efficient use of limited financial resources. To implement such a comprehensive management system will require a commitment from AKDOT&PF administrators, as well as the development of the required procedures. In order to accomplish these goals, the University of Alaska Fairbanks was contracted in the Phase I study to review existing unstable slope programs used by several state DOTs and foreign countries, and to recommend procedures for evaluating unstable slope hazard and risk and the establishment of a statewide database.

The important aspects of an effective unstable slope management program (USMP) are its ability to identify and prioritize hazard and risk associated with unstable slopes, and to provide decision makers with pertinent information to design remedial methods. As part of the unstable slope asset management study, we have developed a set of field survey forms for the evaluation of potential and problematic slopes. These proposed forms have been reviewed by the senior-level AKDOT&PF geotechnical and geological staff, and revised several times; however, by no means are they final. These forms will require further field testing and verification before full implementation.

The next sections describe the parameters used in each step of the field survey procedures. Appendix B contains this information in a user's manual format.

3.1 Preliminary Slope Rating Form for M&O

While the USMP is in operation, M&O personnel will be the first responders to most slope failures. Their involvement is vitally important to the success of the program. The Preliminary Slope Rating Form for M&O, shown in Figure 3.1, provides key risk information of a failed slope in a straightforward manner; this information otherwise may be lost after M&O cleans up the failure. Upon receiving the M&O report, the geotechnical engineer or engineering geologist responsible for USMP in his or her region will conduct an additional assessment.

There are three types of information requiring the M&O crew's judgment: (1) ditch effectiveness; (2) impact on traffic; and (3) historical activity. Each of these categories will be discussed in more detail in the following sections.

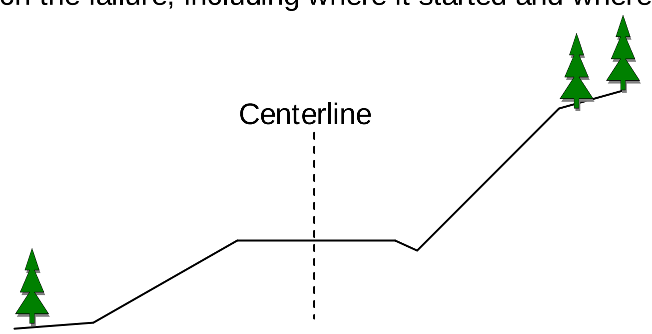
Region (CR, NR, SE)	
Road Name	
Nearest Community	
GPS Coordinates: Latitude	
Longitude	
Approximate CDS Milepoint	

Incident Reported by	
Date	
Phone No / E-Mail	
M&O Station	

Equipment Used (check box and list)		
	DOT&PF Owned:	
	Rental:	
Hours to Clear:		

Material Type (check all that apply)		
Rock	Soil	Fill

Slope Location (sketch the failure, including where it started and where it stopped):



For each category, select the appropriate description:

Ditch Effectiveness		100% containment; no material on pavement	Mostly contained; minor amount on paved shoulder	Debris on shoulder and nearest lane	Debris blocking one or more lanes
Impact on Traffic		Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; detour required
Historical Activity	Material falls on roadway…	Less than once a year	1 to 2 times a year	3 to 6 times a year	More than 6 times a year
	Maintenance required…	Once every 5 years	Once every 2 to 4 years	1 to 2 times a year	3 or more times a year
	Quantity (for soil) or Dimension (for rock) removed per event…	Less than 3 yd^3 or < 1 ft	3 – 6 yd^3 or 1 - 2 ft	6 – 12 yd^3 or 2 - 5 ft	More than 12 yd^3 or > 5 ft

Figure 3. Proposed Preliminary Slope Rating Form for M&O

3.1.1 General Site Information

Region (CR, NR, SE)	
Road Name	
Nearest Community	
GPS Coordinates: Latitude	
Longitude	
Approximate CDS Milepoint	

Incident Reported by	
Date	
Phone No / E-Mail	
M&O Station	

Equipment Used (check box and list)		
	DOT&PF Owned:	
	Rental:	
Hours to Clear:		

Material Type (check all that apply)		
Rock	Soil	Fill

The first step in conducting a preliminary rating of a failed slope is to establish the general site information. The GPS coordinates (i.e. latitude and longitude) for the midpoint of the failure site should be recorded using a decimal degree format with a precision of at least five decimal places. The midpoint of the failure site also should be recorded using the Alaska Coordinated Data System (CDS) Milepoint. These coordinates will allow regional engineers or geologists to locate the slope site without confusion later when they conduct a detailed field survey. Additionally, it is important to have a record of who is reporting the slope failure, in case follow-up clarifications are necessary.

Slope failure is a complex process, in which more than one type of materials may be involved. The M&O personnel need to identify all types of material that have fallen or accumulated in the ditch. The personnel also should indicate the type of equipment used and how many hours it took to clear the site. Engineers and geologists will use this data for statistical analysis of the major types of slope failures in each region and along each roadway, and to determine costs associated with the slope failures.

3.1.2 Ditch Effectiveness

Ditch Effectiveness	100% containment; no material on pavement	Mostly contained; minor amount on paved shoulder	Debris on paved shoulder and nearest lane	Debris blocking one or more lanes

A ditch is a catchment area between the edge of roadway pavement and the base of an adjacent slope that is used to prevent falling rock or sliding soil/debris from reaching the roadway. A ditch is an important cut slope feature that reduces the risk associated with unstable slopes. An effective ditch design must take into account the volume and momentum of the falling or sliding soils and debris. However, ditch effectiveness becomes obvious at a failed slope site. When the M&O personnel encounter a failed slope, he or she should observe the following conditions:

1. Is there a ditch in the slope area?
2. Is there a barrier system in the slope area?
3. How much of the falling rock, or sliding soil/debris has been retained in the ditch?
4. What is the average size and volume of falling rock or soil/debris on the pavement?

Based on these observations, the M&O crew should evaluate the ditch effectiveness as:

- Good Catchment – All or nearly all of the falling rocks or sliding soils/debris are retained in the catchment area.
- Moderate Catchment – Most of the falling rocks or sliding soils/debris are contained in the catchment area. A small amount of traversable rock fragments or soils/debris reaches the shoulder.
- Limited Catchment – A good amount of non-traversable rock fragments or soils/debris reaches the shoulder and pavement.
- No Catchment – There is no ditch or the ditch is ineffective. Most of the falling rocks or sliding soils/debris reaches the roadway.

3.1.3 Impact on Traffic

Impact on Traffic	Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; detour required

Impact on traffic is a risk parameter, which also is an indicator used in the cost-benefit analysis. Because of the vast areal coverage of the Alaska road system, delay or detouring often means severe disruption of daily commuting between communities.

Measurement of the impact on traffic involves several parameters such as the failure length of the unstable slope along the roadway, the width of the roadway impacted, the severity of damage to pavement, and the traversability of the unstable area. The M&O personnel, after making observations right after the slope failure, should classify the impact on traffic based on the traffic disruption as:

- No Impact – The pavement damage or road blockage by falling rocks or sliding soils/debris is none or almost not existent. Normal traffic continues at the posted speed limit.
- Moderate Impact - The pavement damage or road blockage by falling rocks or sliding soils/debris interrupts the traffic flow. Motorists must travel at a reduced speed.
- Severe Impact – The nearest lane of an undivided road is completely or nearly completely blocked. Motorists must stop before passing the failed area.
- Extreme Impact - Both lanes of an undivided road are completely blocked. The road is not traversable, and a detour is required.

3.1.4 Historical Activity

Historical Activity	Material falls on roadway…	Less than once a year	1 to 2 times a year	3 to 6 times a year	More than 6 times a year
	Maintenance required…	Once every 5 years	Once every 2 to 4 years	1 to 2 times a year	3 or more times a year
	Quantity (for soil) or Dimension (for rock) removed per event…	Less than 3 yd^3 or <1 ft	3 – 6 yd^3 or 1 – 2 ft	6 – 12 yd^3 or 2 – 5 ft	More than 12 yd^3 or > 5 ft

This category prioritizes the failure frequency of an unstable slope. This information represents the known past slope failures and cleanout activities at the site. This information together with the maintenance cost are fundamental elements of economic analysis.

M&O personnel usually has the best knowledge of the site maintenance history. However, the maintenance personnel responsible for site cleanout in the past may not be present during the initial observations of the slope failure. For this reason, the M&O personnel only is required to provide information related to one of the historical activities: (1) frequency of material reaching the roadway; (2) maintenance frequency; or (3) amount of rocks or soil/debris removed during one event. The M&O personnel is encouraged to complete this category to the best of his or her abilities. Information included here will help to prioritize funding for slope remediation.

3.2 Preliminary Slope Rating (Step 1) Form

The three AKDOT&PF regional offices will assume responsibility of the USMP using the same three-step procedure outlined above. The first step is to eliminate those inherently low hazard slopes and to target those sites warranting detailed investigation. Table 4.1 contains a summary of AKDOT&PF maintenance costs during FY08 and FY09. There were 6,053 incidents associated with rockfall and landslide cleanup in FY08, and 1,621 in FY09. The unit costs were $41 and $214 per incident, respectively. Judging from these unit costs, many of these slope failures were small scale and low risk, and can be eliminated during the preliminary slope rating.

Table 3. Summary of maintenance cost distribution in FY08 and FY09

Activity	Year	Quantity	UOM	Total Cost
Shoulder, slope, and ditch	FY08	4518	mile	$1,730,047
	FY09	5126		$2,048,227
Rock and landslide cleanup	FY08	6053	Incidents	$246,825
	FY09	1621		$347,046

Similar to the preliminary slope rating form for M&O, there are three types of risk-related information required. However, the degree of accuracy for each of the categories needs to be higher than on the M&O form. These types are: (1) ditch effectiveness; (2) impact on traffic; and (3) historical activity. Figure 3.2 is the Preliminary Slope Rating Form.

3.2.1 General Site Information

Slope Inventory ID	Total Score
For next stage, circle one:	A B

Once a target site is located, the immediate step of populating a database is to conduct a preliminary rating. The Slope Inventory ID is a unique identification number that is used in the AKDOT&PF Unstable Slope Management Program for data storage, retrieval, compilation, and processing. The Alaska Coordinated Data System (CDS) route number with the beginning milepoint of the slope site and the year the site is established provides a unique database reference number, which can be linked to other AKDOT&PF data sources. One caveat with this system is that the CDS route number and milepoint for a segment of road may change through time. The following is an example of the Slope Inventory ID:

85000_128.5_2010 (CDS route number_beginning milepoint_year established)

The Preliminary Rating classifies a slope into three classes: A, B, and Not Rated. If the site is a potentially unstable slope that has not yet failed, the two factors "ditch effectiveness" and "impact on traffic" are used to rate it. However, if the site already has experienced movement, the additional factor "historical activity" is needed. Scoring for each of the factors uses an exponential function with the base of 3 to achieve greater separation among the risk levels. A discrete number is given to each factor based on a set of conditions. The total hazard is the sum of all factors. Class A slopes have moderate to high potential to fail, and an adverse impact to the roadway. Class B slopes have low to moderate potential to fail, and the impact to the roadway is minor. The Not Rated slopes have low potential to fail, and would have negligible impact to the roadway if they did fail; however, we feel that it is important to have a record in the database that these slopes were rated. The scoring breakdowns among the three categories are as follows.

For a slope with prior failures or existing movement:

- Class A slope: Total Hazard Score ≥ 108
- Class B slope: $12 <$ Total Hazard Score < 108
- Not Rated slope: Total Hazard Score ≤ 12

For a potential slope:

- Class A slope: Total Risk Score ≥ 162
- Class B slope: $54 <$ Total Risk Score < 162
- Not Rated slope: Total Risk Score ≤ 54

Unstable Slope Asset Management Program
Preliminary Slope Rating – Step 1

Alaska Department of Transportation and Public Facilities

Slope Inventory ID	Total Score
For next stage, circle one:	**A B**

Rated by:
Date:
Phone No / E-mail:

For existing movement:
≥ 108 → 'A' slopes
> 12 & < 108 → 'B' slopes
For potential movement:
≥ 162 → 'A' slopes
> 54 & < 162 → 'B' slopes

Region (CR, NR, SE)			
Road Name			
Community			
Maintenance Station			
Beginning	Longitude		
	Latitude		
	CDS MP		
Ending	Longitude		
	Latitude		
	CDS MP		

Movement Type (For Existing Movement)			√ one
Fall/Raveling			
Topple			
Spread			
Flow			
Slide	Rotational		
	Translational	Planar	
		Wedge	
Embankment Failure			

Material Type	√ one
Rock	
Debris (coarse)	
Earth (fine)	
Fill	

Slope Location	√
Above Roadway	
Below Roadway	
Left Side	
Right Side	
Existing Failure	
Potential Failure	

Comments (use the back of this sheet for additional comments)

Category Rating →		3	9	27	81	SCORE
Ditch Effectiveness		100% containment; no material on roadway	Mostly contained; minor amount on paved shoulder	Debris on paved shoulder and nearest lane	Debris blocking one or more lanes	
Impact on Traffic		Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; detour required	
Accident History/Potential		No accident; or low accident potential	Property damage without injury; or moderate accident potential	Injury; or high accident potential	Fatality; or extremely high accident potential	
For Existing Movement Historical Activity (Choose One)	Material falls on roadway…	Less than once a year	1 to 2 times a year	3 to 6 times a year	More than 6 times a year	
	Maintenance required…	Once every 5 years	Every 2 to 4 years	1 to 2 times a year	More than 3 times a year	
	Quantity (for soil) or Dimension (for rock) removed per event…	Less than 3 yd^3 or < 1 ft	3 – 6 yd^3 or 1 - 2 ft	6 – 12 yd^3 or 2 - 5 ft	More than 12 yd^3 or > 5 ft	

Figure 3. Proposed Preliminary Slope Rating (Step 1) form

A slope with prior failures or existing movement indicates that the level of stability is marginal or critical. Therefore, the breakdowns between each of the three classes are lower than that for a potential slope.

Beginning	Longitude	
	Latitude	
	CDS MP	
Ending	Longitude	
	Latitude	
	CDS MP	

Slope Location	√
Above Roadway	
Below Roadway	
Left Side	
Right Side	
Existing Failure	
Potential Failure	

The location of the slope site is recorded with two systems. The latitude and longitude and approximate CDS milepoint (CDS MP) are recorded for both the beginning and the ending of the slope. The CDS MPs are recorded to the nearest 0.5 miles. The observer needs to face in the direction of increasing CDS MP to determine the beginning and ending of the slope, as distance along the slope will always correspond with increasing CDS MP. Additionally, the location of the slope relative to the centerline of the road is recorded with check boxes (i.e., above or below the roadway, to the right or to the left). To the right or left of centerline is determined by the observer facing in the direction of increasing CDS MP.

The latitude and longitude recorded by GPS should be in the decimal degree format to a precision of at least five decimal places, using the WGS84 datum since this is the current GIS standard. Positive values occur north of the equator and east of the prime meridian to the International Date Line, while negative values occur south of the equator and west of the prime meridian. Both CDS MP and latitude and longitude can be easily mapped to AKDOT&PF's GIS centerlines.

The AKDOT&PF Unstable Slope Management Program provides a proactive process to deal with slope failure prevention. The observer needs to indicate whether the slope is a potential unstable slope or has previous failures or existing movement, using the check boxes.

Movement Type (For Existing Movement)			√ one
Fall/Raveling			
Topple			
Spread			
Flow			
Slide	Rotational		
	Translational	Planar	
		Wedge	
Embankment Failure → Fill			

Material Type	√ one
Rock	
Debris (coarse)	
Earth (fine)	
Fill	

The classification of slope failures provides geotechnical engineers and engineering geologists with a means to identify the main mode of failure in an area. There are difficulties in landslide classification because of different causes, movement types and rates, morphology, and materials involved. For this reason, landslide classifications are usually based on somewhat subjective selective factors. The classification is based on the type and rate of movement and type of materials involved. The movement types are divided into five categories: fall/raveling, topple, spread, flow, and slide. The sixth type, embankment failure, describes the failure in a high fill. On occasion, a slope failure may involve more than one type of material and a complex mode of movement. The observer needs to determine the predominant type of movement and material at a given site.

3.2.2 Ditch Effectiveness

Category Rating	3	9	27	81
Ditch Effectiveness	100% containment; no material on roadway	Mostly contained; minor amount on paved shoulder	Debris on paved shoulder and nearest lane	Debris blocking one or more lanes

A ditch is a catchment area between the edge of roadway pavement and the base of an adjacent slope that is used to prevent falling rock or sliding soil/debris from reaching the roadway. Ditch effectiveness is an important parameter in the rating of slopes. Slopes that have a high potential to fail may not pose a significant risk, if well-designed ditches are present.

In estimating the ditch effectiveness, the observer should consider several factors that will affect the function of a ditch. These are:

- Slope height
- Slope angle
- Ditch width, depth, and shape
- Anticipated block size and/or quantity of rockfall or soil/debris sliding
- Slope irregularities and the possibility that they will act as launching features with the ability of compromising the benefits expected from a fallout area
- Effect of existing remedial measures, such as barriers

In several state unstable slope management programs, the effectiveness of a ditch is the ratio between the required dimensions based on the Ritchie Ditch Criteria (Ritchie 1963) and the actual ditch dimensions at the site. Figure 3.3 illustrates the ideal ditch width (WR) and depth (DR) at different slope angles and slope heights. For example, for a 50-ft high, 3V:1H cut slope (71.6 slope angle), the Ritchie criteria calls for a 6-ft deep, 18-ft wide ditch. The evaluation of ditch effectiveness involves the measurement of the slope angle, slope height, actual ditch depth (DA) below pavement level, and actual ditch width (WA) from the pavement edge to the beginning of the cut face. The sums of depth and width for the ideal ditch and for the actual ditch are compared. The ditch effectiveness ratio (which equals DR+WR / DA+WA) increases from 1.0 for complete containment upward to infinity for a hypothetical condition of no ditch dimensions. The Ritchie criteria, however, do not consider massive rockfalls or landslides. Its application in this study is limited only to rockfall, and should be used with caution.

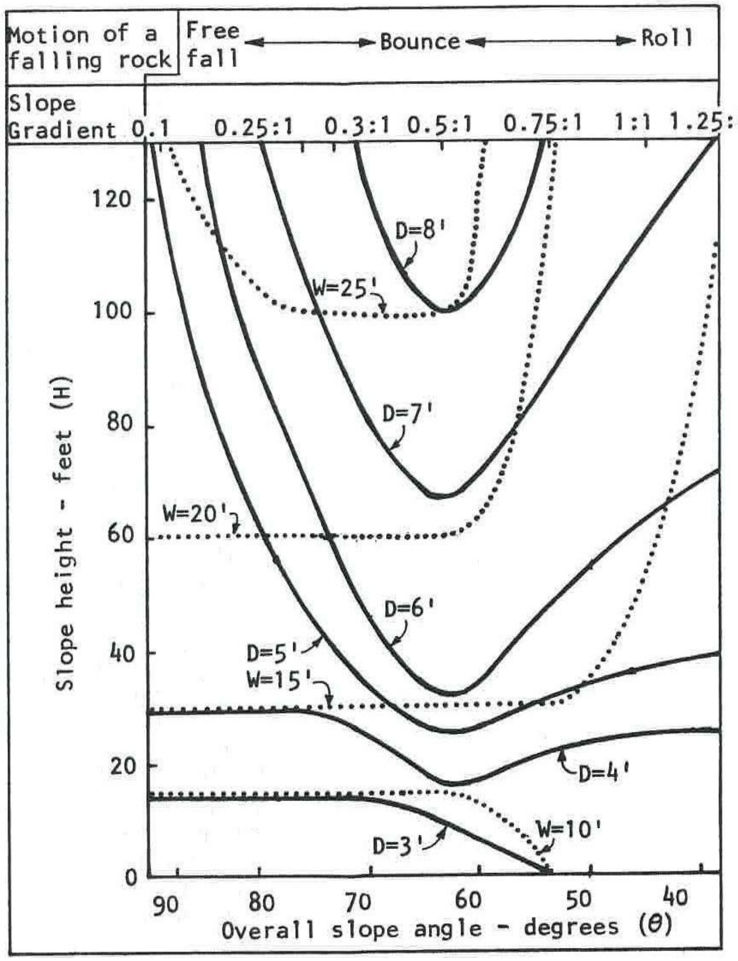


Figure 3. Ritchie ditch criteria - Ditch Design Chart (taken from Golder 1988)

Besides the ditch dimensions, valuable information related to ditch effectiveness may be obtained from the DOT record or by interviewing M&O personnel. While estimating the volume of a sliding mass, the observer should take into account a swell factor, which varies from 12% for sand and gravel, 40% for clay, to 40% to 70% for rock. Scoring the ditch effectiveness should be consistent with the following description:

- Good Catchment (Score = 3): All or nearly all falling rocks or sliding soils/debris are retained or expected to be retained in the catchment area. For rockfall, the ditch effectiveness ratio is less than or equal to 1.0.
- Moderate Catchment (Score = 9): Most of the falling rocks or sliding soils/debris are contained or expected to be contained in the catchment area. A small amount of traversable rock fragments or soils/debris reaches the paved shoulder. For rockfall, the ditch effectiveness ratio is between 1.0 and 3.0.
- Limited Catchment (Score = 27): A good amount of non-traversable rock fragments or soils/debris reaches or is expected to reach the paved shoulder and pavement. For rockfall, the ditch effectiveness ratio is between 3.0 and 9.0.

- No Catchment (Score = 81): There is no ditch or the ditch is ineffective. Most of the falling rocks or sliding soils/debris reaches or will reach the roadway. For rockfall, the ditch effectiveness ratio is greater than 9.0.

3.2.3 Impact on Traffic

Category Rating	3	9	27	81
Impact on Traffic	Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; detour required

Impact on traffic is a risk parameter, which also is an indicator used in the cost-benefit analysis. Because of the vast areal coverage of the Alaska road system, delay or detouring often means severe disruption of daily commuting between communities.

Measurement of the impact on traffic involves several parameters such as the failure length of the unstable slope along the roadway, the width of the roadway impacted, the severity of damage to pavement, and the traversability of the unstable area. The observer should classify the impact on traffic based on the traffic disruption as:

- No Impact (Score = 3): The pavement damage or road blockage by falling rocks or sliding soils/debris is none or almost not existent. Normal traffic continues at the posted speed limit.
- Moderate Impact (Score = 9): The pavement damage or road blockage by falling rocks or sliding soils/debris interrupts the traffic flow. Motorists must travel at a reduced speed.
- Severe Impact (Score = 27): The nearest lane of an undivided road is completely or nearly completely blocked. Motorists must stop before passing the failed area.
- Extreme Impact (Score = 81): Both lanes of an undivided road are completely blocked. The road is not traversable, and a detour is required.

3.2.4 Accident History/Potential

Category Rating	3	9	27	81
Accident History/Potential	No accident; or low accident potential	Property damage without injury; or moderate accident potential	Injury, or high accident potential	Fatality, or extremely high accident potential

This category rates the type of accidents that have occurred near an unstable slope site in the last 10 years. The types of accidents include property and/or vehicle damage, injury, and fatality. While observing a potential unstable site, the accident potential is rated based on the likelihood of a failure event affecting the adjacent structures, property, and motorists. The observer should rate this category based on either the accident types during the last 10 years or its likelihood to cause an accident as:

- Score = 3: There are no recorded accidents near the unstable slope site, or a potential slope failure is unlikely to cause an accident.

- Score = 9: There is a recorded accident near the unstable slope site in the last 10 years, which involved property damage but no injuries; or a potential slope failure is likely to cause property damage.
- Score = 27: There is a reported accident near the unstable slope site in the last 10 years, which involved injuries; or a potential slope failure is likely to cause injury.
- Score = 81: There is a reported accident near the unstable slope site in the last 10 years, which involved a fatality; or a potential slope failure is likely to cause property damage and injury.

3.2.5 Historical Activity

Category Rating		3	9	27	81
For Existing Movement Historical Activity (Choose One)	Material falls on roadway…	Less than once a year	1 to 2 times a year	3 to 6 times a year	More than 6 times a year
	Maintenance required…	Once every 5 years	Every 2 to 4 years	1 to 2 times a year	More than 3 times a year
	Quantity (for soil) or Dimension (for rock) removed per event…	Less than 3 yd^3 or < 1 ft	3 – 6 yd^3 or 1 - 2 ft	6 – 12 yd^3 or 2 - 5 ft	More than 12 yd^3 or > 5 ft

The risk analysis can be conducted at many levels ranging from qualitative to quantitative evaluations. This category rates the failure frequency and impact of an unstable slope, and represents the known past slope failures and cleanout activities at the site. It provides the decision maker with a basis for measuring the risk level and setting the risk priority. This information along with maintenance costs are fundamental elements of economic analysis.

Maintenance records are the best source of information. When neither records nor M&O personnel responsible for site cleanout are available, guidance is necessary for estimating the rockfall/landslide history. The amount of material in the ditch, number of impact marks on the pavement caused by rolling rocks, and the presence of rock/debris in the road are some of the indicators that can be used.

The observer provides information related to one of the historical activities:
(1) frequency of material reaching the roadway; (2) maintenance frequency; or (3) amount of rocks or soil/debris removed during one event. The rating table shown above contains descriptions of the rating criteria.

3.3 Slope Hazard Assessment (Step 2) Form

In the preliminary rating, a slope is classified as one of the three classes based on its total score. The slopes rated as A and B are advanced to the next level of evaluation, and slopes in the Not Rated class will not be evaluated further due to their low failure potential and low risk to motorists. In Steps 2 and 3, the A and B slopes receive detailed assessment based on two categories – hazard and risk. Without prior knowledge of the number of potential unstable slope sites along the state roadway system, it is uncertain how many resources and time a survey team will need to complete the assessment for all unstable slopes. Based on our experience, we estimate that it will take less than one hour for a trained engineer or geologist to conduct the hazard and risk surveys for any given site.

Figure 3.4 is the proposed Slope Hazard Assessment form. It involves two sets of categories: (1) material-dependent categories; and (2) common categories for all types of materials.

3.3.1 General Site Information

Slope Inventory ID	**Total Hazard Score**
For next stage, circle one: S E R	

The Slope Inventory ID is the same ID used in the Preliminary Slope Rating Form (Step 1). See Section 3.2.1 for a description of this number.

The Total Hazard Score varies depending on the type of slope: a rock slope (R) may have a maximum rating of 729; an embankment (E) may have a maximum score of 486; and a soil slope may have a maximum rating of 567. These ranges in ratings, however, do not indicate different levels of hazard severity. Instead, they stem from the different sets of criteria used in rating each type of slope. For example, there are nine criteria for rating rock slope hazard, six criteria for an embankment, and seven criteria for soil slopes. The Total Hazard Score is further divided into four hazard classes.

For soil slopes:

- Class I Hazard: Total Hazard Score ≤ 21
- Class II Hazard: 21 < Total Hazard Score ≤ 63
- Class III Hazard: 63 < Total Hazard Score ≤ 189
- Class IV Hazard: 189 < Total Hazard Score ≤ 567

For embankment failures:

- Class I Hazard: Total Hazard Score ≤ 18
- Class II Hazard: 18 < Total Hazard Score ≤ 54
- Class III Hazard: 54 < Total Hazard Score ≤ 162
- Class IV Hazard: 162 < Total Hazard Score ≤ 486

Unstable Slope Asset Management Program
Slope HAZARD Rating – Step 2

Alaska Department of Transportation and Public Facilities

Slope Inventory ID	Total Hazard Score
For next stage, circle one: S E R	

Rated by:
Date:

Category Rating →				3	9	27	81	SCORE
√ one	Soil or Intermediate Geomaterial (IGM) slopes	√ one						
			Unfrozen	Slope contains minor (<20%) of fine-grained soils; mainly consists of well-graded sand and gravel	Mostly (>80%) fine-grained soil (silt)	Completely fine-grained soil (silt and/or clay)	Mixed slope, containing boulders and/or >20% cobbles	
			Frozen	Coarse-grained (sand and gravel), low ice content, temp colder than 28°F	Coarse-grained (sand and gravel), high ice content, temp warmer than 28°F	Fine-grained (silt, clay, organics), low ice content, temp colder than 28°F	Fine-grained (silt, clay, organics), high ice content, temp warmer than 28°F	
		Slope Angle		Less than 30°	30° - 40°	Use Rating = 81 if slope angle is greater than 40°		
		Maximum Slope Height		≤ 15 ft	15 - 25 ft	25 - 40 ft	≥ 40 ft	
	Embankment	Maintenance Frequency		Once every 5 years	Every 2 to 4 years	1 or 2 times a year	More than 3 times a year	
		Vertical or Horizontal Roadway Displacement		Visible crack or dip	Less than 1 inch	1 to 3 inches	Greater than 3 inches	

TABLE CONTINUES ON NEXT PAGE

Figure 3. Proposed Slope Hazard Rating (Step 2) form

			Category Rating →	3	9	27	81	SCORE
√ one	Rock	Discontinuity Characteristics	Discontinuity Orientation (daylight angle)	Discontinuous joints, favorable orientation (non-daylighting)	Discontinuous joints, fair orientation (< 35°)	Discontinuous joints, unfavorable orientation (> 35°)	Continuous joints, unfavorable orientation (> 35°)	Average:
			Discontinuity Weathering	*Slight:* <20% discoloration, rock retains original texture, grain contact tight	*Moderate:* >20% discoloration, joint contains infilling, grain contact partially open	*High:* Complete discoloration, partially pitted, grain contact partially separate	*Decomposed:* Surface shows soil-like characteristics, grain contact completely separate	
			Discontinuity Roughness	*Rough:* Large angular to vertical asperities on surface	*Undulating:* Asperities are visible and can be felt with the hand	*Planar:* Smooth to the touch	*Clay infilling or slickensided*	
		Slope Angle		1:1 Slope (< 45°)	1:1 to ½:1 slope (45° - 63°)	½:1 to ¼:1 slope (63° - 76°)	¼:1 to Vertical Slope (>76°)	
		Maximum Slope Height		≤ 30 ft	30 -50 ft	50 - 65 ft	> 65 ft	
Water Seepage/Surface Drainage				Dry, no flow	Damp, no free water present	Dripping water	Continuous water flow	
Annual Freeze-Thaw Days				Less than 50 days	50 to 70 days	70 to 125 days	Greater than 125 days	
Slope Movement	Block size / Volume per event			Less than 1 ft / Less than 3 yd^3	1 - 2 ft / 3-6 yd^3	2 - 5 ft / 6-12 yd^3	Greater than 5 ft / Greater than 12 yd^3	
	√ one		Historical Activity	Once every 2 to 4 years	1 to 2 times a year	3 to 6 times a year	7 times a year or more	
			Potential	Slope movement unlikely to happen	Slope movement unlikely to reach pavement	Slope movement possible, but with low frequency	Slope movement possible, and with high frequency	

Figure 3.4 (continued) Proposed Slope Hazard Rating (Step 2) form

For rock slopes:

- Class I Hazard: Total Hazard Score ≤ 27
- Class II Hazard: 27 < Total Hazard Score ≤ 81
- Class III Hazard: 81 < Total Hazard Score ≤ 243
- Class IV Hazard: 243 < Total Hazard Score ≤ 729

3.3.2 Soil or Intermediate Geomaterial (IGM) Slopes

Category Rating			3	9	27	81
Soil or Intermediate Geomaterial (IGM) slopes	√ one	Unfrozen	Slope contains minor (<20%) of fine-grained soils; mainly consists of well-graded sand and gravel	Mostly (>80%) fine-grained soil (silt)	Completely fine-grained soil (silt and/or clay)	Mixed slope, containing boulders and/or >20% cobbles
		Frozen	Coarse-grained (sand and gravel), low ice content, temp colder than 28°F	Coarse-grained (sand and gravel), high ice content, temp warmer than 28°F	Fine-grained (silt, clay, organics), low ice content, temp colder than 28°F	Fine-grained (silt, clay, organics), high ice content, temp warmer than 28°F
	Slope Angle		Less than 30°	30° - 40°	Use Rating = 81 if slope angle is greater than 40°	
	Maximum Slope Height		≤ 15 ft	15- 25 ft	25 - 40 ft	≥ 40 ft

This portion of the table is used to evaluate unstable soil or Intermediate Geomaterial (IGM) slopes. Because of the significant difference in material properties, soil or IGM slopes are evaluated separately from rock slopes. The type of soil, existence of frozen soil, cut slope angle, and the maximum cut slope height are the rating criteria. The observer should use his or her best judgment to complete this evaluation. Soil temperature cannot be determined without field measurement. However, the geographic location of a slope site may give an indication of the ground as “warm” or “cold” permafrost.

Unfrozen soil slopes: Many factors are responsible for different types of slope movement. These include geology, slope gradient and aspect, vegetation cover, soil strength properties, drainage patterns, and weathering. In this evaluation, unfrozen soil slope stability is assessed based on typical compressive strength and friction angle, as well as the potential hazard to motorists. A mixture of boulders and cobbles in a slope represents a high hazard to motorists and is rated with the highest score. Slopes composed of well-graded sand and gravel have high compressive strength and high friction angles, thus posing a lower hazard to motorists. The strength of a completely fine-grained soil may change as it becomes wet, and thus represents a moderate hazard. Each of the rating criteria is summarized below:

- Score = 3: Slope contains minor (<20%) fine-grained soils; mainly consists of well-graded sand and gravel. The slope has adequate stability and represents a minor hazard to motorists.
- Score = 9: Mostly (>80%) fine-grained soil (silt) with low to moderate failure potential and representing a minor hazard to motorists.
- Score = 27: Completely fine-grained soil (silt and/or clay) with moderate failure potential and representing a moderate hazard to motorists.
- Score = 81: Mixed slope, containing boulders and/or >20% cobbles. The slope represents a high hazard to motorists and it adversely affects the roadway or nearby structures.

Frozen soil slopes: Permafrost exists throughout most of Alaska, ranging in thickness from less than a foot at its southern margin to over 2,000-feet thick in the Arctic Coastal Plain. Local variations in thickness, areal extent, and permafrost temperature depend on differing thermal properties of soil and local variations in climate, topography, vegetation, hydrology, and the rate of heat flow within the ground. As permafrost temperature increases, the amount of unfrozen water in it increases exponentially; this reduces the strength properties of frozen soil.

In this category, frozen soil slopes are evaluated based on the soil temperature, ice content, and overall size of soil particles. The threshold temperature separating "warm" and "cold" permafrost is 28^{o}F. Frozen soil with a temperature colder than 28^{o}F has a significantly lower unfrozen water content, resulting in higher strength than warmer frozen soil. Soil with low ice content has better grain contacts, lower creep potential, and higher strength than soil with high ice content. This category is rated as follows:

- Score = 3: Coarse-grained (sand and gravel), low ice content, temperature colder than 28^{o}F with adequate stability.
- Score = 9: Coarse-grained (sand and gravel), high ice content, temperature warmer than 28^{o}F with low to moderate failure potential.
- Score = 27: Fine-grained (silt, clay, organics), low ice content, temperature colder than 28^{o}F with moderate failure potential.
- Score = 81: Fine-grained (silt, clay, organics), high ice content, temperature warmer than 28^{o}F with high failure potential.

Slope angle: The slope angle is the angle between the horizontal plane and the mean plane of the slope face. The slope angle can be measured using different methods, such as: (1) field measurement using an inclinometer or Brunton pocket transit; (2) using photographs; or (3) by manual estimation. With experience, an observer can estimate the slope angle with precision. The slope angle is important because the failure potential increases with an increasing slope angle. The friction angle of cohesionless soil is the sole factor affecting slope stability. As the slope angle approaches the soil friction angle (i.e. angle of repose), the slope becomes critical (FS = 1.0). Beyond the friction angle, the stability decreases rapidly and levels off at an angle about 60^{o} (see Figure 3.5). This

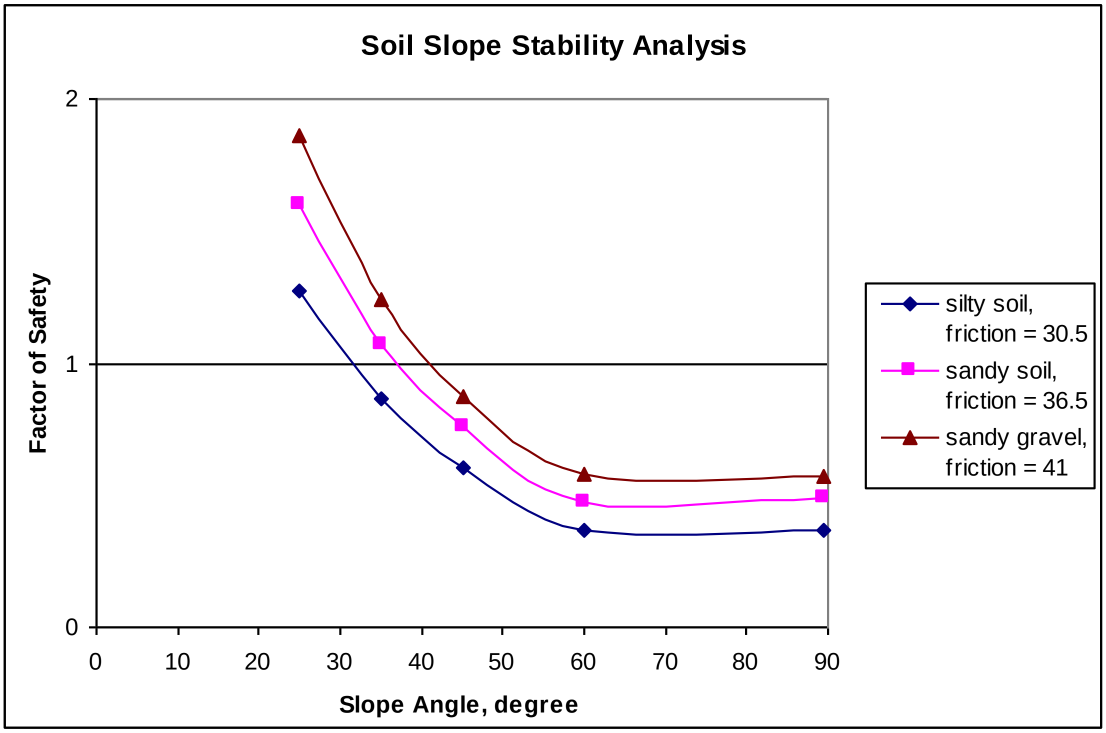


Figure 3. Variation of soil slope stability versus slope cut angle for three types of cohesionless soil

trend is common for the cohesionless soils encountered in Alaska. Typical friction angles for soil range between 26^o for silt and 41^o for gravel with some sand. The rating criteria are based solely on the soil friction angle.

- Score = 3: A soil slope less than 30^o should maintain its stability because typical friction angles are higher than 30^o.
- Score = 9: Slope angles between 30^o and 40^o have low failure potential.
- Score = 81: Any soil slope greater than 40^o is potentially unstable, and represents a high hazard.

Maximum slope height: This category evaluates the potential hazard of slope height. A sliding soil mass moving down a high slope has greater potential energy than the same mass moving down a lower slope. The higher the potential energy, the greater distance the soil mass can travel to reach the roadway; thus, higher slopes represent greater hazards and receive higher ratings.

The maximum vertical height from the base of the slope to the highest point on the cut slope face should be measured. If, however, the sliding soil originates from the natural slope above the cut, the additional vertical height should be included in the measurement. Slope height can be measured using different methods: (1) using photographs; (2) by field estimation; (3) using trigonometric relationships in the field; or (4) using a sighting level and rangefinder. Slope height is divided into four sub-categories as shown in the above table.

3.3.3 Embankment Failures

Category Rating		3	9	27	81
Embankment	Maintenance Frequency	Once every 5 years	Every 2 to 4 years	1 or 2 times a year	More than 3 times a year
	Vertical or Horizontal Roadway Displacement	Visible crack or dip	Less than 1 inch	1 to 3 inches	Greater than 3 inches

Fill failures caused by sliding represent a special type of landslide. They occur primarily in or at the base of an embankment. The causative factors are similar to soil slopes. Fill failures differ from fill settlement, which lacks noticeable horizontal movements. The observer needs to differentiate between these differences. In Alaska, climate-related parameters (e.g. thawing of permafrost, frost heave of base/sub-base materials) also may cause similar displacement features of the pavement. Some features associated with embankment failures are: (1) tension cracks on the roadway; (2) dips in the guardrails; (3) dips in the drive lanes; (4) blocked culverts; and (5) surface water next to the toe of an embankment. Embankment failures are rated based on maintenance frequency and roadway displacement as summarized above.

3.3.4 Rock Slopes

Category Rating			3	9	27	81
Rock	Discontinuity Characteristics	Discontinuity Orientation (daylight angle)	Discontinuous joints, favorable orientation (non-daylighting)	Discontinuous joints, fair orientation (< 35°)	Discontinuous joints, unfavorable orientation (> 35°)	Continuous joints, unfavorable orientation (> 35°)
		Discontinuity Weathering	*Slight:* <20% discoloration, rock retains original texture, grain contact tight	*Moderate:* >20% discoloration, joint contains infilling, grain contact partially open	*High:* Complete discoloration, partially pitted, grain contact partially separated	*Decomposed:* Surface shows soil-like characteristics, grain contact completely separate
		Discontinuity Roughness	*Rough:* Large angular to vertical asperities on surface	*Undulating:* Asperities are visible and can be felt with the hand	*Planar:* Smooth to the touch	*Clay infilling or slickensided*
	Slope angle		1:1 Slope (< 45°)	1:1 to ½:1 slope (45° - 63°)	½:1 to ¼:1 slope (63° - 76°)	¼:1 to Vertical Slope (>76°)
	Maximum Slope Height		≤ 30 ft	30 - 50 ft	50 – 65 ft	≥ 65 ft

Geologic conditions often govern rock slope stability. Structurally controlled failure modes are planar slides, wedge slides, and toppling failures, while the weathering controlled failure modes are differential weathering and raveling. The AKDOT&PF Unstable Slope Management Program characterizes all potential rock failure modes at a slope site, and rates the potential hazard accordingly. Characteristics unique to structurally controlled failures are the orientation and inclination of discontinuities and the roughness of discontinuity surfaces (i.e. micro- and macro-friction). Discontinuities include joints, faults, bedding, schistosity, fracture surfaces, and shear zones, with joints being the most common. Weathering increases the instability of slopes in many ways. Rockfall and raveling happen as weathering erodes decomposed rockmass and allows rock blocks to fall.

Discontinuity Characteristics: Discontinuity characteristics include orientation, degree of weathering, and roughness of discontinuity surfaces. These three parameters are used to assess the stability of rock slopes based on the favorable or unfavorable dip angle and direction, and strength properties (i.e. friction angle and cohesion) of the rockmass. The observer needs to rate all three parameters and obtain the average score that represents the overall discontinuity characteristics rating.

<u>Discontinuity Orientation:</u> Attributes of discontinuities are one of the determinant elements controlling rock slope stability. Figure 3.6 illustrates the effects of joint dip angle on the stability of a 75-ft high rock slope at a range of cut angles from 2:1 to vertical. The values for cohesion and friction angle used in Figure 3.6 are typical for poor to fair quality rockmass. The dip direction of the joint is in the same direction as the

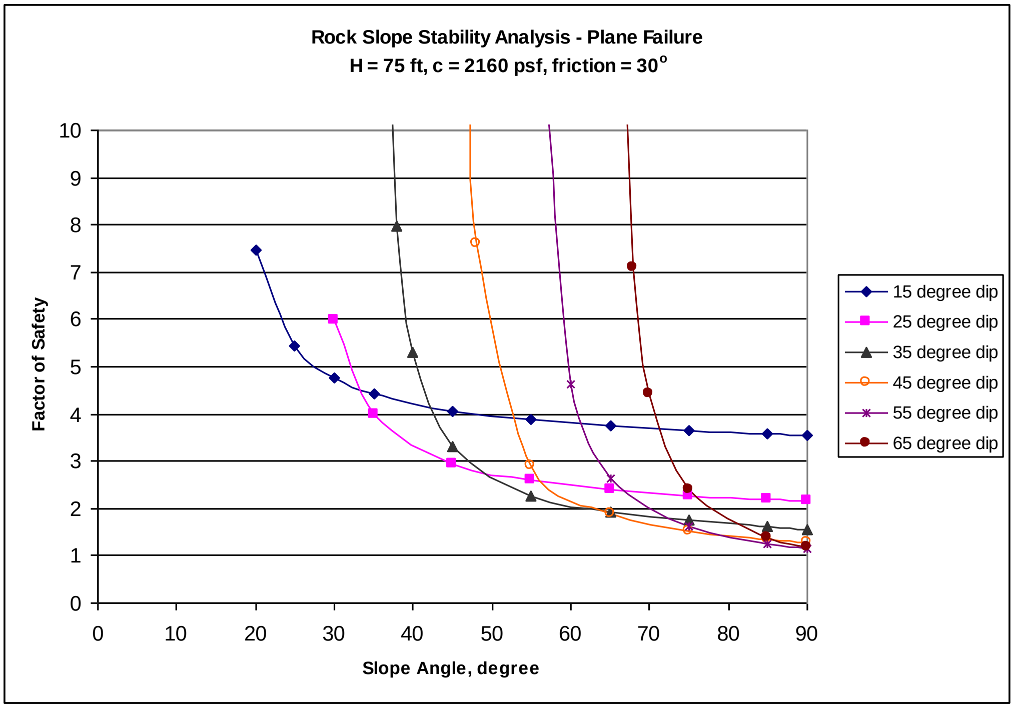


Figure 3. Plane failure analysis of a 75-ft high slope with one joint dipping in the same direction as the slope face

slope face direction. A second example (Figure 3.7) shows how a rock wedge affects the stability of a 75-ft rock slope. In this example, the plunge direction of the rock wedge is in the same direction as the slope face. Based on this analysis, a dip or plunge angle of 35° is the threshold value separating marginal and non-marginal slopes. Discontinuity length is applied as a qualifier to further refine the rating.

In this category, a slope with a prominent joint set dipping into the slope mass (i.e., non-daylighting) with average length of less than 10 ft is considered stable, and receives a score of 3. A discontinuous joint refers to a joint less than 10 ft in length. Rock slopes exhibiting mostly plane- or wedge-blocks formed by discontinuous joints dipping into the slope at angles less than 35° (i.e., fair orientations) receive a score of 9. When plane- or wedge-blocks dip out of slopes at angles higher than 35°, the slope stability deteriorates. Slopes with this condition receive a score of 27. Any slope with a prominent joint set or sets dipping out of the slope at angles greater than 35° and with and average length greater than 10 ft receive a score of 81.

<u>Discontinuity weathering:</u> Weathering increases the instability of slopes in many ways. For example, physical and chemical weathering alters rockmass strength and causes deterioration of slope stability. As the degree of weathering increases, some of the rock blocks on the slope surface become unsupported and start to fall. Differential erosion causes oversteepening that leads to rock raveling. This type of slope failure is common in sedimentary rock that contains erodable layers interbedded with layers that are more resistant to weathering.

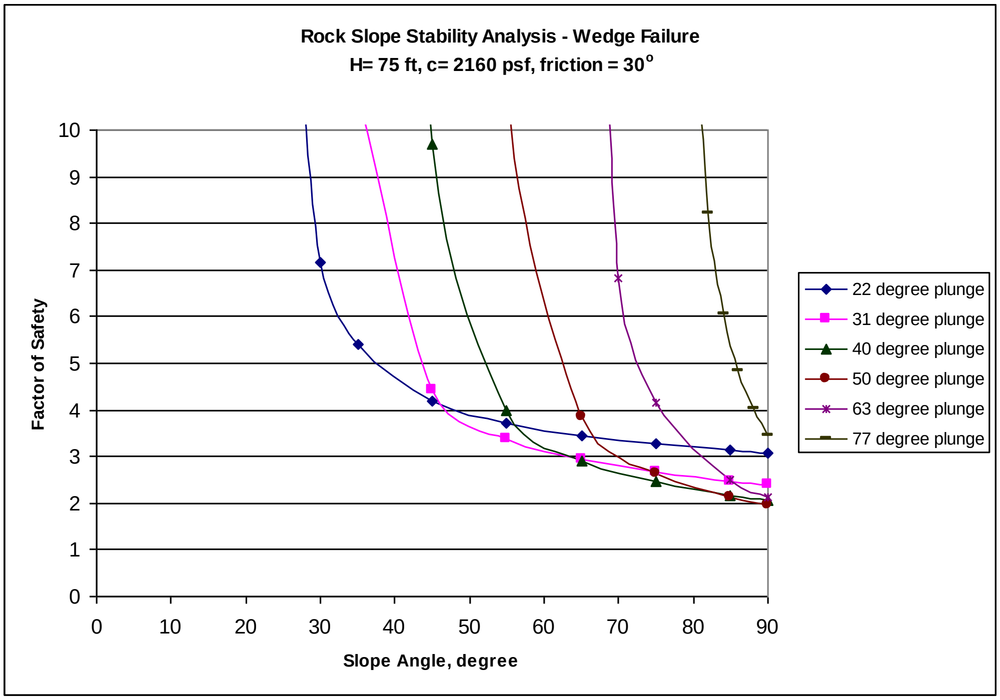


Figure 3. Wedge failure analysis of a 75-ft high slope with rock wedge plunging in the same direction as the slope face

In the field, the observable weathering features are the extent of discoloration of joint surfaces, changes of rock texture, infilling materials, and grain contacts. Based on these weathering features, this category is divided as follows:

- *Slight* (Score = 3): < 20% discoloration, rock retains its original texture, grain contacts are tight
- *Moderate* (Score = 9): > 20% discoloration, joint contains infilling, grain contacts are partially open
- *High* (Score = 27): Complete discoloration, partially pitted, grain contacts are partially separate
- *Decomposed* (Score = 81): Surface shows soil-like characteristics, grain contacts are completely separate

Discontinuity Roughness: Rock friction affects the potential for a rock block to move along a discontinuity. Friction along a discontinuity is governed by the macro- and micro-roughness (i.e. waviness and asperities, respectively). Macro-roughness is the degree of undulation of the discontinuity surface relative to the direction of movement. It indicates the residual shear strength of jointed rockmass. Micro-roughness is a localized phenomenon. It represents the profile of a joint surface. Rock slope failure potential may be greater for slickensided, or clay-gouged rock, than for rock with rough joint surfaces. The micro- and macro-roughness of a joint surface susceptible to planar failure or wedge failure is measured by visual inspection. Sometimes, it can be done with the aid of friction profiles. This category is scored as follows:

- *Rough* (Score = 3): Large angular to vertical asperities on the joint surface, irregular joint surface causing interlocking
- *Undulating* (Score = 9): Asperities are visible and can be felt with the hand, no interlocking
- *Planar* (Score 27): Smooth to the touch, no waviness
- *Clay infilling or slickensided* (Score = 81): Low friction material infilling such as clay separating joint surfaces and negating any roughness of the joint surface (slickensided joints have very low friction angles)

Slope angle: The slope angle is the angle between the horizontal plane and the mean plane of the slope face. The slope angle can be measured using different methods, such as: (1) field measurement using an inclinometer or Brunton pocket transit; (2) using photographs; or (3) by manual estimation. With experience, an observer can estimate the slope angle with precision. The slope angle is important because the failure potential increases with an increasing slope angle. As illustrated in Figures 3.6 and 3.7, the slope angle affects the failure potential non-linearly. For any particular plane or wedge orientation, there is a critical slope angle. Beyond the critical angle, the factor of safety decreases rapidly.

For jointed rockmass, the friction angle ranges from greater than 45^o for very good quality rock to about 30^o for fair quality rock. Friction angles less than 30^o are possible for poor to very poor quality rock. The cohesion ranges from greater than 58 psi to about 36 psi for very good to fair quality rock. Very poor quality rock (i.e., soil-like) has a cohesion of less than 14 psi. Based on the friction and cohesion of the jointed rockmass, this category is scored as follows:

- Score = 3: A slope cut less than 1:1 ($< 45^o$) should maintain its stability.
- Score = 9: Slope cuts from 1:1 to ½:1 (45^o - 63^o) have a low failure potential.
- Score = 27: Slope cuts from ½:1 to ¼:1 (63^o - 76^o) have a moderate failure potential.
- Score = 81: Any rock slope with a cut angle from 1/4:1 to vertical ($> 76^o$) is potentially unstable.

Maximum slope height: This category scores the potential hazard of slope height. Sliding/falling rock blocks on high slopes have greater potential energy than moving blocks on lower slopes. The higher the potential energy, the greater distance the block can travel, possibly reaching the roadway; thus, higher slopes represent greater hazards and receive higher ratings. Pierson et al. (2001) reported that higher cut slopes require wider ditches to catch a certain percentage of rockfalls. In addition, slope height adversely affects the rock slope stability. The higher the slope height, the lower the stability becomes.

The maximum vertical height from the base of the slope to the highest point on the cut slope face should be measured. I f, however, the sliding/falling rock block originates from the natural slope above the cut, the additional vertical height should be included in the measurement. Slope height can be measured using different methods: (1) using photographs; (2) by field estimation; (3) using trigonometric relationships in the field; or (4) using a sighting level and rangefinder. Slope height is divided into four sub-categories as shown in the table above.

3.3.5 Water Seepage / Surface Drainage

Category Rating	3	9	27	81
Water Seepage/ Surface Drainage	Dry, no flow	Damp, no free water present	Dripping water	Continuous water flow

Water and freeze-thaw cycles contribute to the rockmass weathering and change the rockmass strength. Both of these climatic parameters are rated separately. Water seepage or water on soil slope surfaces is an indication of the degree of saturation in the soil mass. Water in cracks and joints in rock reduces the effective stress acting at the base of the sliding block. On occasion, it initiates slope movement by generating an additional horizontal water pressure. This category is determined by visual observations, where water is known to flow continuously or intermittently from the slope. The rating table above contains descriptions of the rating criteria.

3.3.6 Annual Freeze-Thaw Days

Category Rating	3	9	27	81
Annual Freeze-Thaw Days	Less than 50 days	50 to 70 days	70 to 125 days	Greater than 125 days

Rock strength decreases exponentially as the number of freeze-thaw cycle increases (Hale and Shakoor 2003). The annual freeze-thaw days were established by reviewing the daily climatic data from 1971 to 2000. The National Climatic Data Center at NOAA divides the State of Alaska into nine regions. Each freeze-thaw day is defined as a 24-hour period during which the daily maximum temperature is above 32^{o}F and the daily minimum temperature dips below 32^{o}F. This data is used because of the long data collection period and wide distribution of weather stations across Alaska.

Because of large geographic regions with very different climatic patterns in Alaska, the observer needs to choose the annual freeze-thaw days closest to the slope site from the list below.

Annual Freeze-Thaw Days (Select a value closest to the slope site):

1) *Southeast:* Juneau (97 days); Ketchikan (102 days)
2) *Southcentral*: Kodiak (180 days); Valdez (78 days)
3) *Southwest*: Cold Bay (157 days)
4) *Copper River Valley*: Gulkana (84 days)
5) *Cook Inlet:* Anchorage airport (70 days); Homer (119 days): Talkeetna (90 days)
6) *Bristol Bay:* King Salmon (87 days)
7) *West Central:* Bethel (50 days); Nome (42 days)
8) *Interior*: Fairbanks airport (63 days); Big Delta (57 days); Cantwell: 88 days

9) *Arctic*: Barrow (35 days)

Based on the climatic data and the adverse effect of freeze-thaw cycles on rock strength, break points are identified, which provide a reasonable distribution of hazard ratings as summarized in the above table. This category also should be used for soil slopes and embankments. It is the general understanding that repeated freeze-thaw cycles decrease soil particle size and overall strength.

3.3.7 Slope Movement – Block Size or Volume per Event

Category Rating		3	9	27	81
Slope Movement	Block size ----------- volume per event	6-12 inches ----------- Less than 3 yd^3	1-2 ft --------- 3-6 yd^3	2-5 ft ----------- 6-12 yd^3	Greater than 5 ft ---------------- Greater than 12 yd^3

Block size affects the hazard potential since larger blocks have greater kinetic energy than smaller ones. This measurement should be representative of the dominant failure mechanism at the site. If individual rock blocks are typical of the slope failure, measure or estimate the maximum dimension of the largest rock block. If the unstable slope consists of soil, IGM, or debris, the volume of the sliding material per event should be estimated. It is best to obtain this information from the corresponding M&O station. If the data is unavailable, block size or volume per event can be based on visual assessments of the site. While estimating the amount of sliding mass, the observer should take into account of the swell factor, which varies from 12% for sand and gravel, 40% for clay, and 40% to 70% for rock. If the observer is uncertain about the type of failure, he or she should use the mode that gives the higher score. The rating table above contains descriptions of the rating criteria.

3.3.8 Slope Movement – Historical Activity or Potential

Category Rating			3	9	27	81
Slope Movement	√ one	Historical Activity	Once every 2 to 4 years	1 to 2 times a year	3 to 6 times a year	7 times a year or more
		Potential	Slope movement unlikely to happen	Slope movement unlikely to reach pavement	Slope movement possible, but with low frequency	Slope movement possible and with high frequency

This category scores the failure frequency of an unstable slope or the probability of future slope movement. The historical activity information represents known previous slope failures and cleanout activities at the site. This information and the maintenance costs are the elements of economic analysis. Maintenance records are the best source of information. When neither records nor M&O personnel responsible for site cleanout are available, guidance is necessary for estimating the rockfall/landslide history. The amount of material in the ditch, number of impact marks on the pavement caused by rolling rocks, and the presence of rock/debris in the road are some of the indicators that can be used. On the Slope Hazard Rating form (Step 2), the frequency of rockfall or landslide activity is rated differently than on the Preliminary Slope Rating form (Step 1); the net effect is a conservative approach at the early stage of assessment process.

The evaluation of potential slope movement is subjective. However, with a detailed field survey of site geology and structure, climate and water condition, cut slope and natural slope geometry, the observer will have a better grasp of the slope site and can make a meaningful evaluation.

3.4 Slope Hazard Assessment (Step 2) Form

The Slope Risk Assessment Form (see Figure 3.8) contains four categories dedicated to establishing the risk to roadway facilities and motorists, and two categories that rate the severity of slope hazard and the maintenance frequency or annual maintenance cost.

3.4.1 General Site Information

Initial Assessment Summary				
Preliminary (max 243)	Hazard (max 486-567)			**RISK (max 486)**
	S	E	R	

Recommended Action:	
Comments:	

Post-remediation Assessment				
	Hazard (max 486-567)			**RISK (max 486)**
	S	E	R	

Recommended Action:	
Comments:	

The Slope Risk Assessment Form requires the observer to transfer the preliminary and hazard rating results to summary blocks at the top of the form. For the hazard assessment, the observer should identify the type of slope problem (i.e., S = soil slope; E = embankment; R = rock slope). The total risk is the sum of six risk categories discussed below. The maximum total risk is 486, and the minimum is 18. Recommended action should be made according to the policy set by the AKDOT&PF administration or a committee overseeing the Unstable Slope Asset Management system. Recommended action can include a wide range of activities from "no action" to "cost-benefit analysis" to "slope remediation." If an unstable slope is remediated, it should be re-assessed using the Slope Risk Assessment form. Post-remediation assessment scores are summarized in the second tier of blocks at the top of the form.

Slope Inventory ID	Initial Assessment Summary						
	Preliminary (max 243)	Hazard (max 486-567)			**RISK (max 486)**	Recommended Action:	
		S	E	R		Comments:	
	Post-remediation Assessment						
		Hazard (max 486-567)			**RISK (max 486)**	Recommended Action:	
		S	E	R		Comments:	

Rated by:	
Date:	

Category Rating	3	9	27	81	SCORE
Hazard Class (use the score from Hazard Rating form)	*Class I*: Soil and Rock Slope ≤ 21 Embankment ≤ 18	*Class II:* 21 < Soil and Rock Slope ≤ 63 18 < Embankment ≤ 54	*Class III:* 63 < Soil and Rock Slope ≤ 189 54 < Embankment ≤ 162	*Class IV:* 189 < Soil and Rock Slope ≤ 567 162 < Embankment ≤ 486	
Impact on Traffic	Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; long detour required	
Annual Average Daily Traffic (AADT)	< 500	500 – 4,000	4,000 – 10,000	> 10,000	
Average Vehicle Risk (AVR)	< 25%	25% - 50%	50% - 75%	> 75%	
% Decision Sight Distance (PDSD)	Adequate (100%)	Moderate (80-99%)	Limited (60-79%)	Very Limited (< 60%)	
Maintenance Response: Frequency or Cost	Once every 5 years or less	Once every 2 to 4 years	1 to 2 times a year	3 times a year or more	
	< $2,000	$2,000-$5,000	$5,000-$25,000	> $25,000	

Figure 3. Proposed Slope Risk Assessment (Step 3) form

3.4.2 Hazard Class

Category Rating →	3	9	27	81
Hazard Class (use the score from Hazard Rating form)	*Class I*: Soil and Rock ≤ 21 Emb. ≤ 18	*Class II:* 21 < Soil and Rock ≤ 63 18 < Emb. ≤ 54	*Class III:* 63 < Soil and Rock ≤ 189 54 < Emb. ≤ 162	*Class IV:* 189 < Soil and Rock ≤ 567 162 < Emb. ≤ 486

The rating of the Hazard Class needs to be transferred from the Slope Assessment Form. The Total Hazard Score varies depending on the type of slope: a rock or soil slope (R or S) may have a maximum rating of 567, and an embankment (E) may have a maximum score of 486. These ranges in ratings, however, do not indicate different levels of hazard severity. Instead, they stem from the different sets of criteria used in rating each type of failures. For example, there are seven criteria for rating a rock or soil slope hazard, and six criteria for an embankment. The Total Hazard Score is further divided into four hazard classes.

For soil and rock slopes:

- Class I hazard: Total Hazard Score ≤ 21
- Class II hazard: 21 < Total Hazard Score ≤ 63
- Class III hazard: 63 < Total Hazard Score ≤ 189
- Class IV hazard: 189 < Total Hazard Score ≤ 567

For embankment failures:

- Class I hazard: Total Hazard Score ≤ 18
- Class II hazard: 18 < Total Hazard Score ≤ 54
- Class III hazard: 54 < Total Hazard Score ≤ 162
- Class IV hazard: 162 < Total Hazard Score ≤ 486

3.4.3 Impact on Traffic

Category Rating →	3	9	27	81
Impact on Traffic	Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; long detour required

This category rates the impedance of traffic due to a slope failure. Impact on traffic is a risk parameter that is included in cost-benefit analysis. Because of the vast areal coverage of the Alaska road system, delay or detouring often means severe disruption of daily commuting between communities. Table 3.2 summarizes the detour distance at some of the key points along the Alaskan roadway system. As indicated, there are several highways and highway segments without any possibility of detouring, and many with detour distances over several hundred miles.

Measurement of the impact on traffic involves several parameters such as the failure length of the unstable slope along the roadway, the width of the roadway impacted, the

Table 3. Summary of detour distances along the Alaska highway system

Highway Name	Hwy Segment with No Detour			Origin (City/Jct.)	Destination (City/Jct.)	Detour Route	Detour Start	Detour (miles)	Normal (miles)	Difference (miles)
	Length (miles)	MP Start	MP End							
Dalton Hwy.	414	0	414	Elliot Hwy Jct.	Dead horse	No Detour Available				
Elliot Hwy.	152	0	152	Manley Hot Springs	Fox	No Detour Available				
Steese Hwy.	161	0	161	Fairbanks	Circle	No Detour Available				
Richardson Total	366	0	366	Old Valdez	Fairbanks	No Detour Available				
Richardson	115	0	115	Valdez	Glenn Hwy Jct	Detour Involves Marine Hwy.				
Richardson	14	115	129	Glenn/Richardson Jct.	Tok Cutoff Jct.	Detour Tok to Anchorage	Tok	562	328	234
Richardson	57	129	186	Glenn/Tok Cutoff Jct.	Paxson	Detour Glennallen to Delta Jct.	Tok	233	137	96
Richardson	80	186	266	Paxson	Delta Jct.	Detour Glennallen to Delta Jct.	Tok	233	151	82
Richardson	96	266	362	Richardson/Alaska Hwy Jct	Fairbanks	Detour Delta Jct. to Fairbanks	Delta Jct.	664	96	568
Parks	175	35	210	Glenn/Parks Jct.	Cantwell/Denali Hwy.	Detour Glenn/Parks Jct. to Fairbanks	Glenn/Parks Jct.	520	323	197
Parks	148	210	358	Cantwell/Denali Hwy.	Fairbanks	Detour Glenn/Parks Jct. to Fairbanks	Glenn/Parks Jct.	520	323	197
Denali Hwy.	134	0	134	Denali/Richardson Jct.	Denali/Parks Jct.	Detour Cantwell to Paxson (summer)	Cantwell	324	134	190
Tok Cutoff	125	0	125	Gakona Jct.	Tok	Detour Glennallen to Tok	Gakona Jct.	245	125	120
Glenn Hwy.	154	189	35	Glennallen	Glenn/Parks Jct.	Detour Glennallen to Glenn/Parks Jct.	Glennallen	570	154	416
Glenn Hwy.	35	35	0	Glenn/Parks Jct.	Anchorage	Detour Involves Marine Hwy.				
Seward Hwy.	37	127	90	Anchorage	Girdwood	Detour Involves Marine Hwy.				
Seward Hwy.	11	90	79	Girdwood	Whittier/Portage Road	Detour Involves Marine Hwy.				
Seward Hwy.	22	79	57	Whittier/Portage Road	Hope Hwy.	Detour Involves Marine Hwy.				
Seward Hwy.	20	57	37	Hope Hwy.	Tern Lake Jct.	Detour Involves Marine Hwy.				
Seward Hwy.	37	37	0	Tern Lake Jct.	Seward	Detour Involves Marine Hwy.				
Sterling Hwy.	57	37	94	Tern Lake Jct.	Soldotna	Detour Involves Marine Hwy.				
Sterling Hwy.	79	94	173	Soldotna	Homer	Detour Involves Marine Hwy.				
Edgerton Hwy./McCarthy Road	34	0	34	Richardson Hwy. Jct.	Chitina	No Detour Available				
Edgerton Hwy./McCarthy Road	64	34	98	Chitin	McCarthy	No Detour Available				
Taylor Hwy.	96	0	96	Titling Jct.	Taylor Hwy. Jct.	Detour Titling Jct. Taylor Hwy. Jct.	Whitehorse	799	471	328
Taylor Hwy.	64	96	160	Taylor Hwy. Jct.	Eagle	No Detour Available				

Table 3.2 (continued) Summary of detour distances along the Alaska highway system

Highway Name	Hwy Segment with No Detour			Origin (City/Jct.)	Destination (City/Jct.)	Detour Route	Detour Start	Detour (miles)	Normal (miles)	Difference (miles)
	Length (miles)	MP Start	MP End							
Alaska Hwy.	80	1222	1302	Canadian Border	Titling Jct.	Detour CA Border to Titling Jct.	Whitehorse	508	375	133
Alaska Hwy.	12	1302	1314	Titling Jct.	Tok	No Detour Available				
Alaska Hwy.	108	1314	1422	Tok	Delta Jct.	Detour Tok To Delta Junction	Tok	262	108	154
South Klondike Hwy.	14	0	14	Skagway	Canadian Border	Detour Involves Marine Hwy.				
Haines Hwy.	41	0	41	Haines	Canadian Border	Detour Involves Marine Hwy.				
Glacier Hwy.	2			Point Lena Way (PLW)	Fairhaven	Detour Point Lena Way to Fairhaven	PLW	3	2	1
Glacier Hwy.	0.5			Lena Beach (LB)	Point Lena Way (PLW)	Detour LB to PLW Glacier Jct.	Lena Beach	2.5	0.5	2
Glacier Hwy.	3			Fairhaven	Mendenhall Lap Rd. Jct.	No Detour Available				
Glacier Hwy.	3			Mendenhall Lap Rd. Jct.	Egan Drive	Detour Mendenhall Jct. to Egan Dr	Mendenhall lp. Jct.	6	3	3
Thane Rd	5.3			Thane	Juneau	No Detour Available				
North Douglas Hwy	12			Douglas	Peterson Creek(end)	No Detour Available				
Copper River Hwy	16	0	16	Cordova	Alaganik	No Detour Available				

severity of damage to pavement, and the traversability of the unstable area. Based on field observation shortly after a slope failure, the observer should classify the impact on traffic as:

- No Impact (Score = 3): The pavement damage or road blockage by falling rocks or sliding soils/debris is none or almost not existent. Normal traffic continues at the posted speed limit.
- Moderate Impact (Score = 9): The pavement damage or road blockage by falling rocks or sliding soils/debris interrupts the traffic flow. Motorists must travel at a reduced speed.
- Severe Impact (Score = 27): The nearest lane of an undivided road is completely or nearly completely blocked. Motorists must stop before passing the failed area.
- Extreme Impact (Score = 81): Both lanes of an undivided road are completely blocked. The road is not traversable, and a long detour is required.

3.4.4 Annual Average Daily Traffic (AADT)

Category Rating →	3	9	27	81
Annual Average Daily Traffic (AADT)	< 500	500 – 4,000	4,000 – 10,000	> 10,000

Annual Average Daily Traffic (AADT) is the average daily traffic volume passing by an unstable slope in a period of one year. The AADT is the combined traffic volume in both traveling directions for an undivided roadway. For a divided roadway, AADT is the traffic volume in the lane(s) adjacent to the slope. The average daily traffic typically varies over a given length of highway because of numerous breaks in the traffic pattern. Businesses, shopping centers, recreation areas, and crossroads change the flow and direction of traffic. Table 3.3 is a summary of AADT from the three AKDOT&PF regions from 2006 to 2008, taken from Annual Traffic Reports. Permanent traffic recorders (PTRs) recorded the combined daily traffic. The traffic patterns in the Northern and Central regions were similar, whereas the Southeast had a much lower traffic volume.

Table 3. AADT values for the three AKDOT&PF regions

Region	Combined AADT (vehicles/day)			
	<500	500 - 4000	4000 - 10000	>10000
Southeast	21%	55%	16%	8%
Central	0%	24%	20%	56%
Northern	9%	25%	15%	51%
Statewide	12%	39%	14%	35%

A slope site with a high AADT suggests that a higher number of accidents or higher cost of traffic delay could occur due to slope-related hazards. The AADT also indicates the importance of a roadway. Closing the roadway for cleanout or remediation may affect the regional economy. The daily traffic volume data can be obtained from the AKDOT&PF regional office.

The rating of AADT for a combined two-way traffic volume is as follows:

- Score = 3: < 500 vehicles/day
- Score = 9: 500 – 4,000 vehicles/day
- Score = 27: 4,000 -10,000 vehicles/day
- Score = 81: >10,000 vehicles/day

3.4.5 Average Vehicle Risk (AVR)

Category Rating →	3	9	27	81
Average Vehicle Risk (AVR)	< 25%	25% - 50%	50% - 75%	> 75%

The average vehicle risk (AVR) is the percentage of time that a vehicle is present in the unstable slope zone. The percentage is obtained using a formula based on slope length, AADT, number of lanes, and the posted speed limit through the hazard zone. A rating of 100% implies that on average one vehicle can be expected to pass the hazard zone. A rating higher than 100% means that at any given time more than one vehicle is present within the hazard zone. Once the AVR is calculated, a discrete value is assigned based on the above table. The equation used to calculate AVR is:

$$AVR,\% = \frac{AADT * L}{s * 24} * 100\%$$

Where *AADT* is average daily traffic (vehicles per day), *L* is the length of unstable slope zone (miles), and *s* is the posted speed limit (mi/hr). The 24 converts days to hours.

3.4.6 Percent Decision Sight Distance (PDSD)

Category Rating →	3	9	27	81
% Decision Sight Distance (PDSD)	Adequate (100%)	Moderate (80-99%)	Limited (60-79%)	Very Limited (< 60%)

The percent decision sight distance (PDSD) is the maximum road length that a driver has to identify and avoid a rockfall hazard. The PDSD is critical when obstacles on the road are difficult to perceive, or when unexpected or unusual maneuvers are required. The actual DSD is measured along the edge of pavement in the direction of oncoming traffic. It is the distance from the edge of a hazard zone to where a 6 in. object disappears when viewing the road at a height of 3.5 ft above the ground. The distance is measured in both directions, where both directions of traffic are likely to be affected, and the shorter distance is recorded. The recommended AASHTO Decision Sight Distances are:

Posted Speed (mph)	Decision Sight Distance (ft)
30	450
40	600
50	750
60	1,000
70	1,100

The Percent of Decision Sight distance (PDSD) is determined using the following formula:

$$PDSD,\% = \frac{ASD}{DSD} * 100\%$$

where *ASD* is the actual sight distance (ft) and *DSD* is the decision sight distance (ft).

3.4.7 Maintenance Response (Frequency or Cost)

Category Rating →	3	9	27	81
Maintenance Response: Frequency or Cost	Once every 5 years or less	Once every 2 to 4 years	1 to 2 times a year	3 times a year or more
	< $2,000	$2,000-$5,000	$5,000-$25,000	> $25,000

The economic impact of a slope failure is not easy to evaluate because delay of traffic or detouring can have far-reaching effects to the surrounding communities. Rather than directly determining the economic impacts, indicators of the impacts can be used. Two most reliable indicators are the costs associated with traffic delays and the annual maintenance costs over a 20-year span. A cost-benefit analysis can be made based on the costs of traffic delays and life-cycle maintenance (i.e. 20 years), and the cost to permanently repair the unstable slope. At the present time, AKDOT&PF does not have the complete records to conduct an economic analysis. However, as the database of the 20-year maintenance costs is established, the economic component of the unstable slope asset management system can be improved.

The observer rates this category in terms of the maintenance frequency or annual maintenance cost, whichever data is available.

CHAPTER 4 – IMPLEMENTATION OF AKDOT&PF UNSTABLE SLOPE MANAGEMENT PROGRAM

Implementing a proactive unstable slope management program (USMP) will improve the mitigation of rockfall and landslide hazards throughout the Alaska transportation system through the development and management of a technically relevant asset inventory. Such a program must address the specific needs of the individual state transportation agency. Due to the broad cross section of personnel and environments that will be involved in the program, its technical and managerial advantages clearly must be demonstrated to ensure the necessary level of participation and commitment from those involved.

In this chapter, we present the general recommendations for the development and implementation of the USMP and associated database. Figure 4.1 is a flowchart outlining the procedural framework with general tasks and their associated responsibilities. These recommendations are based on the following assumptions:

1. The general program outline and methods of investigation have been developed;
2. An external consultant will perform the initial database population; and
3. AKDOT&PF will update the database with information pertaining to the changing conditions of the slopes after the initial database population.

4.1 Program Development

The data compilation methods introduced in Chapter 3 are a guide; these methods will need to be further reviewed and modified to ensure that the program meets the needs of AKDOT&PF. Each modification made should increase the overall consistency and accuracy of slope hazard recognition, while employing relevant experience to tailor the program for successful application within AKDOT&PF.

For the first stage of field testing, the consultants will make an initial trial run with the revised program, to identify any procedural issues, and to debug and troubleshoot the format and content of the rating forms. The slopes chosen for this trial run will cover the majority of failure conditions and failure types likely to be encountered throughout the road system of Alaska. Each slope will be rated using the three rating forms (see Chapter 3). The results of the trial run will be analyzed with respect to successful hazard recognition, numerical delineation of hazard severity, the level of detail provided, and how intuitive and user-friendly the rating forms are. The consultants will use these initial results to adjust both the forms and procedures.

The second stage of field testing will serve both as an introduction to the program, and as an opportunity to gain feedback on the procedures and forms from AKDOT&PF personnel (this stage of field testing will be further discussed in Section 4.4 on Training). The consultants will select slopes for this field trial based on conversations with M&O, engineering geologists, geotechnical engineers, and/or materials engineers within each region, in order to determine each Region's "top ten" unstable slopes. The identified slopes will be cross-referenced with the M&O cost database to further sort the slopes based on frequency of activity and associated costs. The selected slopes will be evaluated in the field by the consultants as well as the AKDOT&PF trainees using the three rating forms. The second stage testing results will be analyzed to

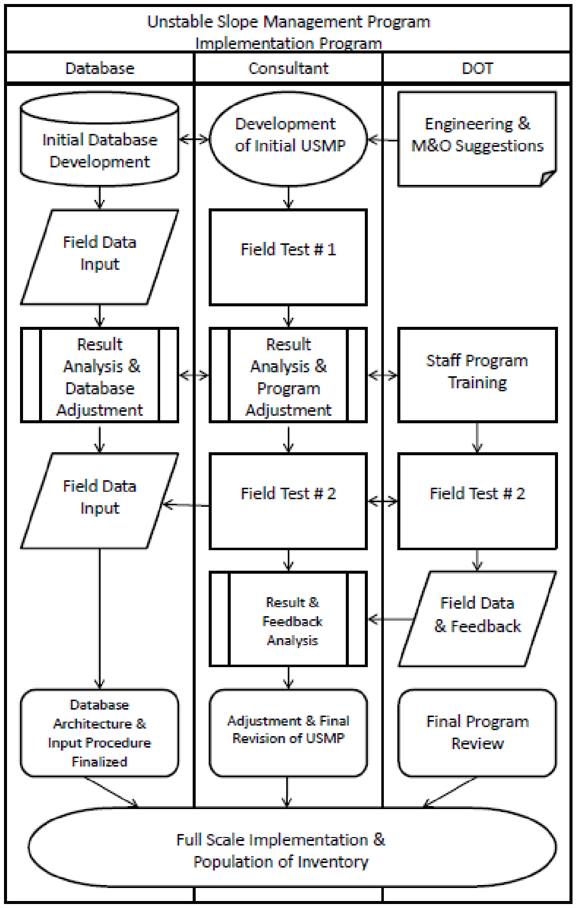


Figure 4. Recommended general framework for USMP and database development

determine the accuracy of hazard recognition, degree of correlation among the various observers, and general user input. The consultants will use the second stage testing results to make final modifications to the forms and procedures. At this point, the USMP will be considered field-tested and ready for full-scale implementation.

4.2 Full-Scale Database Population and Maintenance

The full-scale implementation of the USMP involves the population of the database with a comprehensive list of all slopes that pose either a potential or current risk to the Alaska state roadway system. The database population will be achieved through field data collection in three steps:

1. *Initial slope identification:* The consultants will review a section of roadway using available data, such as historical maintenance activity, landslide-related expenses, and the Roadview Explorer photographic documentation log. The consultants then will drive through the section of roadway with knowledgeable M&O personnel, such as the district foreman, to learn from first-hand experience about the unstable slopes in the area.
2. *Preliminary slope rating:* The identified slopes will be photographed to record their initial condition and surveyed using the Preliminary Slope Rating – Step 1 form.

3. *Slope hazard and risk assessment rating:* Initially, slopes that are identified as "A" slopes will be reassessed during a second trip to the field using the Slope Hazard Assessment –Step 2 and Slope Risk Assessment – Step 3 forms. Depending on the number of "A" slopes, "B" slopes also may be included at this time. This survey will necessitate communication with the associated M&O district personnel to determine historically relevant slope information.

We estimate that the initial inventory will need two to three years to complete. Once the initial database population is complete, the unstable slope inventory must be updated with new slopes created by projects, and maintained with the changing conditions of the existing slopes. The ultimate success of the program relies heavily both on M&O's initial observations of unstable slope movements, and on personnel in each AKDOT&PF region dedicated to the database maintenance. The continual addition of information to the database will provide accurate and time-relevant information for decisions concerning mitigation and funding.

4.3 GIS Database

With the extensive amount of data created by the USMP and the need for effective analysis, an interactive database that can be spatially and visually linked to the state road network is essential. A GIS program, such as ArcMap, can provide spatial and temporal analysis. The final visual and analysis components of the database software should be determined though consultation with AKDOT&PF personnel to ensure compatibility, while taking advantage of existing software expertise. This database should serve as a tool from which information can be easily accessed for incorporation into related design projects, maintenance, and asset management.

While the final structure and organization of the database will require significant input from AKDOT&PF personnel, some key features of the database organization and interfacing should include:

- Both region-specific and stateside views
- Visual and spatial representation of information
- Searchable database
- Built-in safety checks to prevent data loss
- Temporal and spatial analysis
- Ability to update existing information as conditions change
- Consistently stable system within all intended uses
- Web-based portal abilities allowing remote uploading and analysis
- User-friendly interface

4.4 Training

The success of the USMP is dependent on the efforts of a broad spectrum of people involved, includes personnel from Design and Engineering, Maintenance and Operations, and Information and Technology. Staff training will promote accurate and reliable data collection for both new unstable slopes and updating existing slopes after the inventory has been completed.

Training will consist of both classroom and hands-on field training. The classroom training will consist of an overview of the program, accompanied by a PowerPoint presentation using relevant photographs to identify material types, failure types, and the various attributes associated with each. Within the classroom, photographic case studies will accompany each rating form, as well as step-by-step instructions on how to complete each field on the form.

The hands-on field training will be conducted concurrently with the second stage of field testing, by evaluating the “top ten” unstable slopes in each Region (see Section 4.1). The hands-on field training will expose AKDOT&PF personnel to the complete USMP field procedure and the use of all three rating forms. This training session also will provide valuable user feedback for the final modifications of the program.

Database training should include the personnel who will be doing data entry and/or accessing the data for design needs. Even with a well-designed database and user-friendly interface, training will ensure uniformity in data input and allow the full use of the system capabilities. Levels of training will vary depending on the familiarity of the trainees to the base software.

CHAPTER 5 – REFERENCES

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State Hwy Name & No. ______________________________

Beginning M. P. ____________________

L or R of Centerline *

Ending M. P. ______________________

Preliminary Rating

Cut Class A or B *

Proposed Correction_________________

____

County Name & No. ____________________

Date of Rating (YYMMDD)________________

Posted Speed Limit ______________________

ADT ________________________________

Rater________________________________

Cost Estimate $_________________________

Preliminary Rating Remarks: (Continue on Back) ______________________________

____

DETAILED RATING

Slope Height Score ________________________

Slope Height in Feet________________________

Ditch Effectiveness Score ___________________

Catchment Letter G M L N *

Average Vehicle Risk Score _________________

Percent of time ____________________________

Site Distance Score _______________________

Percent Design Value _____________________

Site Distance _____________________________

Roadway Width Score _____________________

Roadway Width in Feet ____________________

GEOLOGIC CHARACTER CASE 1

Structural Condition Score _________________

Fracture Letter D C *

Orientation Letter F R A *

Rock Friction Score ______________________

Friction Letter R I U P C S *

GEOLOGIC CHARACTER CASE 2

Structural Condition Score__________________

Erosion Feature Letter F O N M *

Diff in Erosion Rate Score _________________

Diff in Erosion Rate Letter S M L E *

Block Size/ Quant. Per Event ______________

Block Size in Feet _________________________

Quantity in Cubic Yards ___________________

Climate & H_2O Score _____________________

Precipitation Letter L M H *

Freezing Period Letter N S L *

Water Letter N I C *

Rockfall History Score _______________

Rockfall History Letter F O M C *

* Circle One

Remarks: ____

____

Figure A.1 Rockfall Hazard Field Data Sheet (adapted from Pierson et al. 1990)

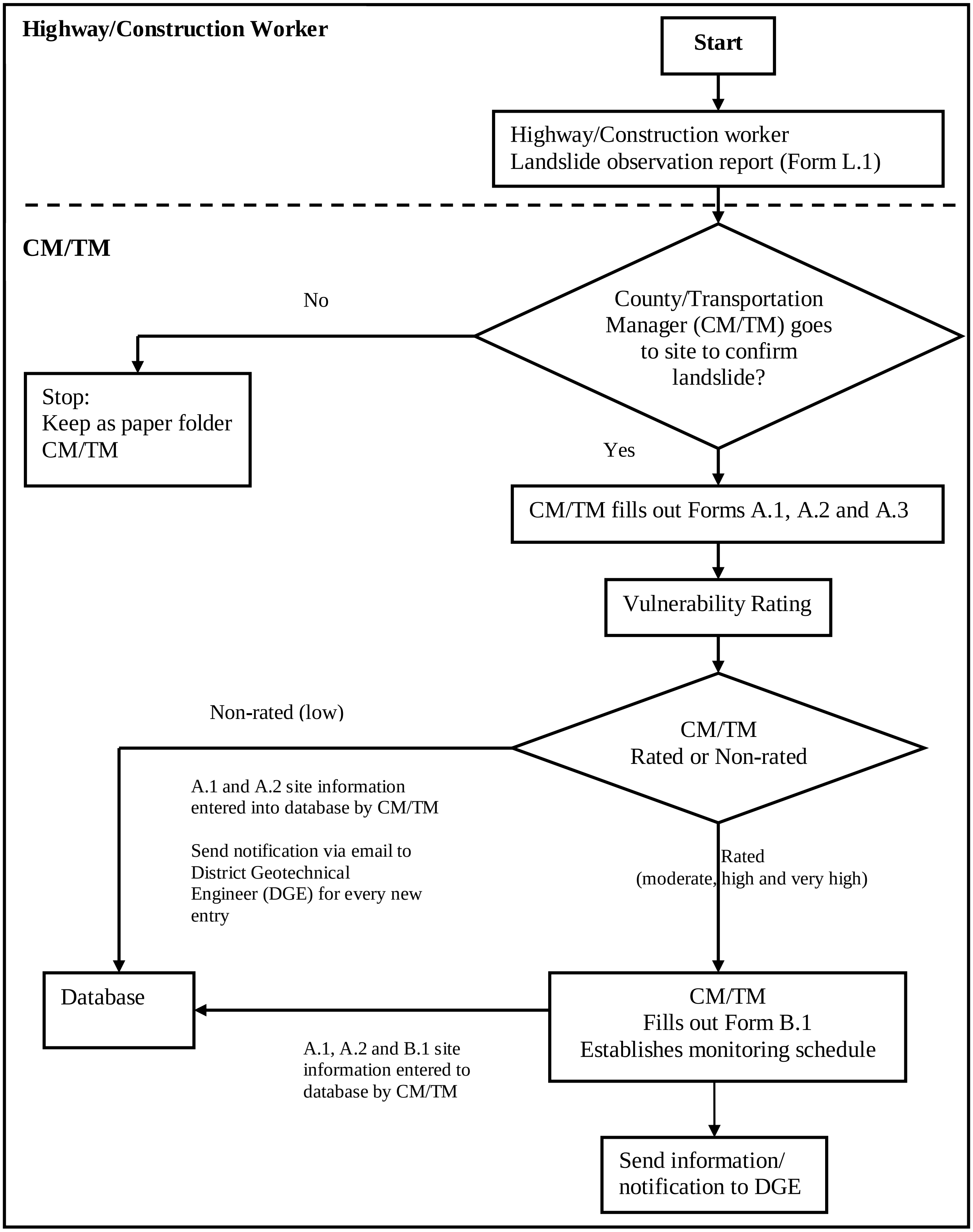

Figure A.2 Landslide reconnaissance process (adapted from Liang 2007)

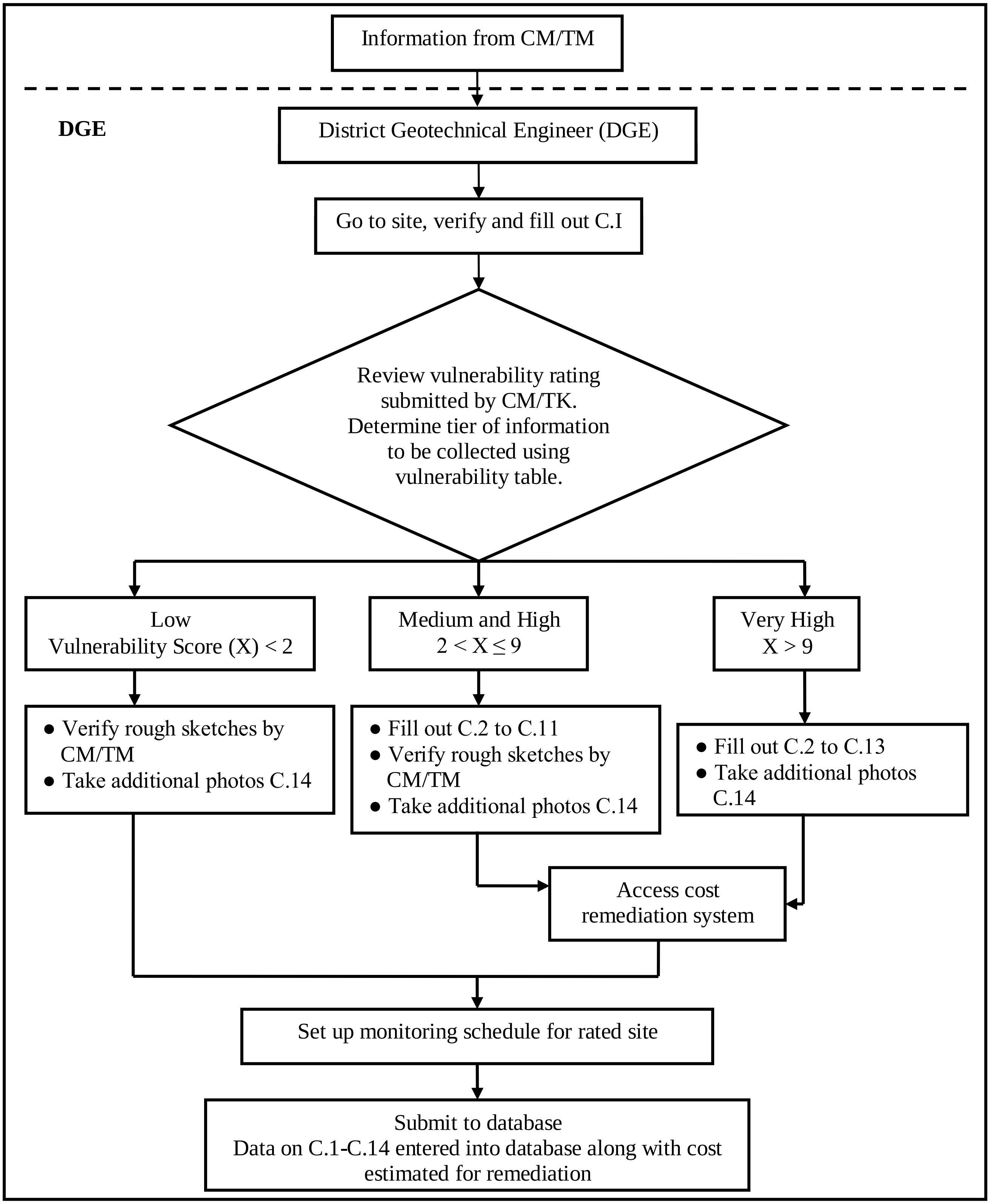

Figure A.2 (continued) Landslide reconnaissance process (adapted from Liang 2007)

B.1 Preliminary Rating Form for AKDOT&PF M&O

Ditch Effectiveness	100% containment; no material on pavement	Mostly contained; minor amount on paved shoulder	Debris on paved shoulder and nearest lane	Debris blocking one or more lanes

A ditch is a catchment area between the edge of roadway pavement and the base of an adjacent slope that is used to prevent falling rock or sliding soil/debris from reaching the roadway. The M&O personnel should observe the following conditions:

Is there a ditch in the slope area?

Is there a barrier system in the slope area?

How much of the falling rock or sliding soil/debris has been retained in the ditch?

What is the average size and volume of falling rock or soil/debris on the pavement?

Based on these observations, the M&O personnel should evaluate the ditch effectiveness as:

- Good Catchment – All or nearly all of the falling rocks or sliding soils/debris are retained in the catchment area.
- Moderate Catchment – Most of the falling rocks or sliding soils/debris are contained in the catchment area. A small amount of traversable rock fragments or soils/debris reaches the shoulder.
- Limited Catchment – A good amount of non-traversable rock fragments or soils/debris reaches the shoulder and pavement.
- No Catchment – There is no ditch or the ditch is ineffective. Most of the falling rocks or sliding soils/debris reaches the roadway.

Impact on Traffic	Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; detour required

Measurement of the impact on traffic involves several parameters such as the failure length of the unstable slope along the roadway, the width of the roadway impacted, the severity of damage to pavement, and the traversability of the unstable area. The M&O personnel, after making observations right after the slope failure, should classify the impact on traffic as:

- No Impact – The pavement damage or road blockage by falling rocks or sliding soils/debris is none or almost not existent. Normal traffic continues at the posted speed limit.
- Moderate Impact - The pavement damage or road blockage by falling rocks or sliding soils/debris interrupts the traffic flow. Motorists must travel at a reduced speed.

- Severe Impact – The nearest lane of an undivided road is completely or nearly completely blocked. Motorists must stop before passing the failed area.
- Extreme Impact - Both lanes of an undivided road are completely blocked. The road is not traversable, and a detour is required.

Historical Activity	Material falls on roadway…	Less than once a year	1 to 2 times a year	3 to 6 times a year	More than 6 times a year
	Maintenance required…	Once every 5 years	Once every 2 to 4 years	1 to 2 times a year	3 or more times a year
	Quantity (for soil) or Dimension (for rock) removed per event…	Less than 3 yd^3 or <1 ft	3 – 6 yd^3 or 1 – 2 ft	6 – 12 yd^3 or 2 – 5 ft	More than 12 yd^3 or > 5 ft

This category prioritizes the failure frequency of an unstable slope. This information represents the known past slope failures and cleanout activities at the site. However, the maintenance personnel responsible for site cleanout in the past may not be present during the initial observations of the slope failure. For this reason, the M&O personnel only is required to provide information related to one of the historical activities: (1) frequency of material reaching the roadway; (2) maintenance frequency; or (3) amount of rocks or soil/debris removed during one event.

B.2 Preliminary Slope Rating Form (Step 1)

Slope Inventory ID	Total Score
For next stage, circle one: A B	

Once a target site is located, the immediate step of populating a database is to conduct a preliminary rating. The Slope Inventory ID is a unique identification number that is used in the AKDOT&PF Unstable Slope Management Program for data storage, retrieval, compilation, and processing. The Alaska Coordinated Data System (CDS) route number with the beginning milepoint of the slope site and the year the site is established provides a unique database reference number, which can be linked to other AKDOT&PF data sources. One caveat with this system is that the CDS route number and milepoint for a segment of road may change through time. The following is an example of the Slope Inventory ID:

85000_128.5_2010 (CDS route number_beginning milepoint_year established)

The Preliminary Rating classifies a slope into three classes: A, B, and Not Rated. If the site is a potentially unstable slope that has not yet failed, the two factors "ditch effectiveness" and "impact on traffic" are used to rate it. However, if the site already has experienced movement, the additional factor "historical activity" is needed. Scoring for each of the factors uses an exponential function with the base of 3 to achieve greater separation among the risk levels. A discrete number is given to each factor based on a set of conditions. The total hazard is the sum of all factors. Class A slopes have moderate to high potential to fail, and an adverse impact to the roadway. Class B slopes have low to moderate potential to fail, and the impact to the roadway is minor. The Not Rated slopes have low potential to fail, and would have negligible impact to the roadway if they did fail; however, we feel that it is important to have a record in the database that these slopes were rated. The scoring breakdowns among the three categories are as follows.

For a slope with prior failures or existing movement:

- Class A slope: Total Hazard Score ≥ 108
- Class B slope: $12 <$ Total Hazard Score < 108
- Not Rated slope: Total Hazard Score ≤ 12

For a potential slope:

- Class A slope: Total Risk Score ≥ 162
- Class B slope: $54 <$ Total Risk Score < 162
- Not Rated slope: Total Risk Score ≤ 54

Beginning	Longitude	
	Latitude	
	MP	
Ending	Longitude	
	Latitude	
	MP	

Slope Location	√
Above Roadway	
Below Roadway	
Left Side	
Right Side	
Existing	
Potential	

The location of the slope site is recorded with two systems. The latitude and longitude and approximate CDS milepoint (CDS MP) are recorded for both the beginning and the ending of the slope. The CDS MP's are recorded to the nearest 0.5 miles. The observer needs to face in the direction of increasing CDS MP to determine the beginning and ending of the slope, as distance along the slope will always correspond with increasing CDS MP. Additionally, the location of the slope relative to the centerline of the road is recorded with check boxes (i.e., above or below the roadway, to the right or to the left). To the right or left of centerline is determined by the observer facing in the direction of increasing CDS MP.

The latitude and longitude recorded by GPS should be in the decimal degree format to a precision of at least five decimal places, using the WGS84 datum since this is the current GIS standard. Positive values occur north of the equator and east of the prime meridian to the International Date Line, while negative values occur south of the equator and west of the prime meridian. Both CDS MP and latitude and longitude can be easily mapped to AKDOT&PF's GIS centerlines.

The AKDOT&PF Unstable Slope Management Program provides a proactive process to deal with slope failure prevention. The observer needs to indicate whether the slope is a potential unstable slope or has previous failures or existing movement, using the check boxes.

Movement Type (For Existing Movement)			√ one
Fall/Raveling			
Topple			
Spread			
Flow			
Slide	Rotational		
	Translational	Planar	
		Wedge	
Embankment Failure			

Material Type	√ one
Rock	
Debris (coarse)	
Earth (fine)	
Fill	

The classification of slope failures provides geotechnical engineers and engineering geologists with a means to identify the main mode of failure in an area. The classification is based on the type and rate of movement and type of materials involved. The movement types are divided into five categories: fall/raveling, topple, spread, flow, and slide. The sixth type, embankment failure, describes the failure in a high fill. On occasion, a slope failure may involve more than one type of material and a complex mode of movement. The observer needs to determine the predominant type of movement and material at a given site.

Category Rating	3	9	27	81
Ditch Effectiveness	100% containment; no material on roadway	Mostly contained; minor amount on shoulder	Debris on shoulder and nearest lane	Debris blocking one or more lanes

A ditch is a catchment area between the edge of roadway pavement and the base of an adjacent slope that is used to prevent falling rock or sliding soil/debris from reaching the roadway. Ditch effectiveness is an important parameter in the rating of slopes. Slopes that have a high potential to fail may not pose a significant risk, if well-designed ditches are present.

In estimating the ditch effectiveness, the observer should consider several factors that will affect the function of a ditch. These are:

- Slope height
- Slope angle
- Ditch width, depth, and shape
- Anticipated block size and/or quantity of rockfall or soil/debris sliding
- Slope irregularities and the possibility that they will act as launching features with the ability of compromising the benefits expected from a fallout area
- Effect of existing remedial measures, such as barriers

Valuable information related to ditch effectiveness may be obtained from the DOT record or by interviewing M&O personnel. Scoring the ditch effectiveness should be consistent with the following description:

- Good Catchment (Score = 3): All or nearly all falling rocks or sliding soils/debris are retained or expected to be retained in the catchment area. For rockfall, the ditch effectiveness ratio is less than or equal to 1.0.
- Moderate Catchment (Score = 9): Most of the falling rocks or sliding soils/debris are contained or expected to be contained in the catchment area. A small amount of traversable rock fragments or soils/debris reaches the paved shoulder. For rockfall, the ditch effectiveness ratio is between 1.0 and 3.0.
- Limited Catchment (Score = 27): A good amount of non-traversable rock fragments or soils/debris reaches or is expected to reach the paved shoulder and pavement. For rockfall, the ditch effectiveness ratio is between 3.0 and 9.0.
- No Catchment (Score = 81): There is no ditch or the ditch is ineffective. Most of the falling rocks or sliding soils/debris reaches or will reach the roadway. For rockfall, the ditch effectiveness ratio is greater than 9.0.

Category Rating	3	9	27	81
Impact on Traffic	Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; detour required

Measurement of the impact on traffic involves several parameters such as the failure length of the unstable slope along the roadway, the width of the roadway impacted, the severity of damage to pavement, and the traversability of the unstable area. The observer should classify the impact on traffic based on the traffic disruption as:

- No Impact (Score = 3): The pavement damage or road blockage by falling rocks or sliding soils/debris is none or almost not existent. Normal traffic continues at the posted speed limit.
- Moderate Impact (Score = 9): The pavement damage or road blockage by falling rocks or sliding soils/debris interrupts the traffic flow. Motorists must travel at a reduced speed.
- Severe Impact (Score = 27): The nearest lane of an undivided road is completely or nearly completely blocked. Motorists must stop before passing the failed area.
- Extreme Impact (Score = 81): Both lanes of an undivided road are completely blocked. The road is not traversable, and a detour is required.

Category Rating	3	9	27	81
Accident History/Potential	No accident; or low accident potential	Property damage without injury; or moderate accident potential	Injury, or high accident potential	Fatality, or extremely high accident potential

This category rates the type of accidents that have occurred near an unstable slope site in the last 10 years. The types of accidents include property and/or vehicle damage, injury, and fatality. While observing a potential unstable site, the accident potential is rated based on the likelihood of a failure event affecting the adjacent structures, property, and motorists. The observer should rate this category based on either the accident types during the last 10 years or its likelihood to cause an accident as:

- Score = 3: There are no recorded accidents near the unstable slope site, or a potential slope failure is unlikely to cause an accident.
- Score = 9: There is a recorded accident near the unstable slope site in the last 10 years, which involved property damage but no injuries; or a potential slope failure is likely to cause property damage.
- Score = 27: There is a reported accident near the unstable slope site in the last 10 years, which involved injuries; or a potential slope failure is likely to cause injury.
- Score = 81: There is a reported accident near the unstable slope site in the last 10 years, which involved a fatality; or a potential slope failure is likely to cause property damage and injury.

Category Rating		3	9	27	81
For Existing Movement Historical Activity (Choose One)	Material falls on roadway…	Less than once a year	1 to 2 times a year	3 to 6 times a year	More than 6 times a year
	Maintenance required…	Once every 5 years	Every 2 to 4 years	1 to 2 times a year	More than 3 times a year
	Quantity (for soil) or Dimension (for rock) removed per event…	Less than 3 yd^3 or < 1 ft	3 – 6 yd^3 or 1 - 2 ft	6 – 12 yd^3 or 2 - 5 ft	More than 12 yd^3 or > 5 ft

This category rates the failure frequency of an unstable slope. This information represents the known past slope failures and cleanout activities at the site. Maintenance records are the best source of information. When neither records nor M&O personnel responsible for site cleanout are available, guidance is necessary for estimating the rockfall/landslide history. The amount of material in the ditch, number of impact marks on the pavement caused by rolling rocks, and the presence of rock/debris in the road are some of the indicators that can be used.

The observer provides information related to one of the historical activities: (1) frequency of material reaching the roadway; (2) maintenance frequency; or (3) amount of rocks or soil/debris removed during one event. The rating table shown above contains descriptions of the rating criteria.

B.3 Slope Hazard Assessment Form (Step 2)

Slope Inventory ID	Total Hazard Score
For next stage, circle one: S E R	

The Slope Inventory ID is the same ID used in the Preliminary Slope Rating Form (Step 1). See the description of this number in Section B.2.

The Total Hazard Score varies depending on the type of slope: a rock slope (R) may have a maximum rating of 729; an embankment (E) may have a maximum score of 486; and a soil slope may have a maximum rating of 567. These ranges in ratings, however, do not indicate different levels of hazard severity. Instead, they stem from the different sets of criteria used in rating each type of slope. For example, there are nine criteria for rating a rock slope hazard, six criteria for an embankment, and seven criteria for soil slopes. The Total Hazard Score is further divided into four hazard classes.

For soil slopes:

- Class I Hazard: Total Hazard Score ≤ 21
- Class II Hazard: 21 < Total Hazard Score ≤ 63
- Class III Hazard: 63 < Total Hazard Score ≤ 189
- Class IV Hazard: 189 < Total Hazard Score ≤ 567

For embankment failures:

- Class I Hazard: Total Hazard Score ≤ 18
- Class II Hazard: 18 < Total Hazard Score ≤ 54
- Class III Hazard: 54 < Total Hazard Score ≤ 162
- Class IV Hazard: 162 < Total Hazard Score ≤ 486

For rock slopes:

- Class I Hazard: Total Hazard Score ≤ 27
- Class II Hazard: 27 < Total Hazard Score ≤ 81
- Class III Hazard: 81 < Total Hazard Score ≤ 243
- Class IV Hazard: 243 < Total Hazard Score ≤ 729

Category Rating		√ one	3	9	27	81
Soil or Intermediate Geomaterial (IGM) slopes	Unfrozen		Slope contains minor (<20%) of fine-grained soils; mainly consists of well-graded sand and gravel	Mostly (>80%) fine-grained soil (silt)	Completely fine-grained soil (silt and/or clay)	Mixed slope, containing boulders and/or >20% cobbles
	Frozen		Coarse-grained (sand and gravel), low ice content, temp colder than 28°F	Coarse-grained (sand and gravel), high ice content, temp warmer than 28°F	Fine-grained (silt, clay, organics), low ice content, temp colder than 28°F	Fine-grained (silt, clay, organics), high ice content, temp warmer than 28°F
	Slope Angle		Less than 30°	30° - 40°	Use Rating = 81 if slope angle is greater than 40°	
	Maximum Slope Height		≤ 15 ft	15- 25 ft	25 - 40 ft	≥ 40 ft

Soil or mixed soil / Intermediate Geomaterial (IGM) slopes

This portion of the table is used to evaluate unstable soil or Intermediate Geomaterial (IGM) slopes. Because of the significant difference in material properties, soil or IGM slopes are evaluated separately from rock slopes. The type of soil, existence of frozen soil, cut slope angle, and the maximum cut slope height are the rating criteria. The observer should use his or her best judgment to complete this evaluation. Soil temperature cannot be determined without field measurement. However, the geographic location of a slope site may give an indication of the ground as "warm" or "cold" permafrost.

Unfrozen soil slopes: Unfrozen soil slope stability is assessed based on typical compressive strength and friction angle, as well as the potential hazard to motorists. A mixture of boulders and cobbles in a slope represents a high hazard to motorists and is rated with the highest score. Slopes composed of well-graded sand and gravel have high compressive strength and high friction angles, thus posing a lower hazard to motorists. The strength of a completely fine-grained soil may change as it becomes wet, and thus represents a moderate hazard. Each of the rating criteria is summarized below:

- Score = 3: Slope contains minor (<20%) fine-grained soils; mainly consists of well-graded sand and gravel. The slope has adequate stability and represents a minor hazard to motorists.
- Score = 9: Mostly (>80%) fine-grained soil (silt) with low to moderate failure potential and representing a minor hazard to motorists.
- Score = 27: Completely fine-grained soil (silt and/or clay) with moderate failure potential and representing a moderate hazard to motorists.

- Score = 81: Mixed slope, containing boulders and/or >20% cobbles. The slope represents a high hazard to motorists and it adversely affects the roadway or nearby structures.

Frozen soil slopes: Frozen soil slopes are evaluated based on the soil temperature, ice content, and overall size of soil particles. The threshold temperature separating "warm" and "cold" permafrost is 28^{o}F. Frozen soil with a temperature colder than 28^{o}F has a lower unfrozen water content, resulting in higher strength than warmer frozen soil. Soil with low ice content has better grain contacts, lower creep potential, and higher strength than soil with high ice content. This category is rated as follows:

- Score = 3: Coarse-grained (sand and gravel), low ice content, temperature colder than 28^{o}F with adequate stability.
- Score = 9: Coarse-grained (sand and gravel), high ice content, temperature warmer than 28^{o}F with low to moderate failure potential.
- Score = 27: Fine-grained (silt, clay, organics), low ice content, temperature colder than 28^{o}F with moderate failure potential.
- Score = 81: Fine-grained (silt, clay, organics), high ice content, temperature warmer than 28^{o}F with high failure potential.

Slope angle: The slope angle is the angle between the horizontal plane and the mean plane of the slope face. The slope angle can be measured using different methods, such as: (1) field measurement using an inclinometer or Brunton pocket transit; (2) using photographs; or (3) by manual estimation. With experience, an observer can estimate the slope angle with precision. The slope angle is important because the failure potential increases with an increasing slope angle. The friction angle of cohesionless soil is the sole factor affecting slope stability. As the slope angle approaches the soil friction angle (i.e., angle of repose), the slope becomes critical (FS = 1.0). Beyond the friction angle, the stability decreases rapidly and levels off at an angle of about 60^{o}. This trend is common for the cohesionless soils encountered in Alaska. Typical friction angles for soil range between 26^{o} for silt and 41^{o} for gravel with some sand. These criteria are based solely on the soil friction angle.

- Score = 3: A soil slope less than 30^{o} should maintain its stability because typical friction angles are higher than 30^{o}.
- Score = 9: Slope angles between 30^{o} and 40^{o} have low failure potential.
- Score = 81: Any soil slope greater than 40^{o} is potentially unstable, and represents a high hazard.

Maximum cut slope height: This category evaluates the potential hazard of slope height. A sliding soil mass moving down a high slope has greater potential energy than the same mass moving down a lower slope. The higher the potential energy, the greater distance the soil mass can travel to reach the roadway; thus, higher slopes represent greater hazards and receive higher ratings.

The maximum vertical height from the base of the slope to the highest point on the cut slope face should be measured. If, however, the sliding soil originates from the natural slope above the cut, the additional vertical height should be included in the measurement. Slope height can be measured using different methods: (1) using photographs; (2) by field estimation; (3) using trigonometric relationships in the field; or (4) using a sighting level and rangefinder. Slope height is divided into four sub-categories as shown in the above table.

However, use only integer values by rounding the calculated scores. The slope height with a calculated score 100 is 62.9 ft. To be consistent with other categories, the observer should assign a score of 81 to any slope higher than 60 ft.

Embankment Failures

Category Rating		3	9	27	81
Embankment	Maintenance Frequency	Once every 5 years	Every 2 to 4 years	1 or 2 times a year	More than 3 times a year
	Vertical or Horizontal Roadway Displacement	Visible crack or dip	Less than 1 inch	1 to 3 inches	Greater than 3 inches

Fill failures caused by sliding represent a special type of landslide. They occur primarily in or at the base of an embankment. The causative factors are similar to soil slopes. Fill failures differ from fill settlement, which lacks noticeable horizontal movements. The observer needs to differentiate between these differences. In Alaska, climate-related parameters (e.g. thawing of permafrost, frost heave of base/sub-base materials) also may cause similar displacement features of the pavement. Some features associated with embankment failures are: (1) tension cracks on the roadway; (2) dips in the guardrails; (3) dips in the drive lanes; (4) blocked culverts; and (5) surface water next to the toe of an embankment. Embankment failures are rated based on maintenance frequency and roadway displacement as summarized above.

Rock Slopes

Category Rating			3	9	27	81
Rock	Discontinuity Characteristics	Discontinuity Orientation (daylight angle)	Discontinuous joints, favorable orientation (non-daylighting)	Discontinuous joints, fair orientation (< 35°)	Discontinuous joints, unfavorable orientation (> 35°)	Continuous joints, unfavorable orientation (> 35°)
		Discontinuity Weathering	*Slight:* <20% discoloration, rock retains original texture, grain contact tight	*Moderate:* >20% discoloration, joint contains infilling, grain contact partially open	*High:* Complete discoloration, partially pitted, grain contact partially separated	*Decomposed:* Surface shows soil-like characteristics, grain contact completely separate
		Discontinuity Roughness	*Rough:* Large angular to vertical asperities on surface	*Undulating:* Asperities are visible and can be felt with the hand	*Planar:* Smooth to the touch	*Clay infilling or slickensided*
	Slope angle		1:1 Slope (< 45°)	1:1 to ½:1 slope (45° - 63°)	½:1 to ¼:1 slope (63° - 76°)	¼:1 to Vertical Slope (>76°)
	Maximum Slope Height		≤ 30 ft	30 - 50 ft	50 – 65 ft	≥ 65 ft

Geologic conditions often govern rock slope stability. Structurally controlled failure modes are planar slides, wedge slides, and toppling failures, while the weathering controlled failure modes are differential weathering, and raveling. The AKDOT&PF Unstable Slope Management Program characterizes all potential rock failure modes at a slope site, and rates the potential hazard accordingly. Characteristics unique to structurally controlled failures are the orientation and inclination of discontinuities and the roughness of the discontinuity surfaces (i.e. micro- and macro-friction). Discontinuities include joints, faults, bedding, schistosity, fracture surfaces, and shear zones, with joints being the most common. Weathering increases the instability of slopes in many ways. Rockfall and raveling occur as weathering erodes the decomposed rockmass and allows rock blocks to fall.

Discontinuity Characteristics: Discontinuity characteristics include orientation, degree of weathering, and roughness of discontinuity surfaces. These three parameters are used to assess the stability of rock slopes based on the favorable or unfavorable dip angle and direction, and strength properties (i.e. friction angle and cohesion) of the rockmass. The observer needs to rate all three parameters and obtain the average score that represents the overall discontinuity characteristics rating.

<u>Discontinuity Orientation:</u> Attributes of discontinuities are one of the determinant elements controlling rock slope stability. A slope with a prominent joint set dipping into the slope mass (i.e., non-daylighting) with average length of less than 10 ft is considered stable, and receives a score of 3. A discontinuous joint refers to a joint less than 10 ft in length. Rock slopes exhibiting mostly plane- or wedge-blocks formed by discontinuous

joints dipping into the slope at angles less than 35^o (i.e., fair orientations) receive a score of 9. When plane- or wedge-blocks dip out of slopes at angles higher than 35^o, the slope stability deteriorates. Slopes with this condition receive a score of 27. Any slope with a prominent joint set or sets dipping out of the slope at angles greater than 35^o and with and average length greater than 10 ft receive a score of 81.

Rockmass Strength, Discontinuity Weathering: Physical and chemical weathering alters the rockmass strength and causes deterioration of slope stability. As the degree of weathering increases, some of the rock blocks on the slope surface become unsupported and start to fall. In the field, the observable weathering features are the extent of discoloration of joint surfaces, changes of rock texture, infilling materials, and grain contacts. Based on these weathering features, this category is divided as follows:

- *Slight* (Score = 3): < 20% discoloration, rock retains its original texture, grain contacts are tight
- *Moderate* (Score = 9): > 20% discoloration, joint contains infilling, grain contacts are partially open
- *High* (Score = 27): Complete discoloration, partially pitted, grain contacts are partially separate
- *Decomposed* (Score = 81): Surface shows soil-like characteristics, grain contacts are completely separate

<u>Discontinuity Roughness:</u> Rock friction affects the potential for a rock block to move along a discontinuity. Friction along a discontinuity is governed by the macro- and micro-roughness (i.e. waviness and asperities, respectively). Macro-roughness is the degree of undulation of the discontinuity surface relative to the direction of movement. It indicates the residual shear strength of the jointed rockmass. Micro-roughness is a localized phenomenon. It represents the profile of a joint surface. Rock slope failure potential may be greater for slickensided or clay-gouged rock, than for rock with rough joint surfaces. The micro- and macro-roughness of a joint surface susceptible to planar failure or wedge failure is measured by visual inspection. Sometimes, it can be done with the aid of friction profiles. This category is scored as follows:

- *Rough* (Score = 3): Large angular to vertical asperities on the joint surface, irregular joint surface causing interlocking
- *Undulating* (Score = 9): Asperities are visible and can be felt with the hand, no interlocking
- *Planar* (Score 27): Smooth to the touch, no waviness
- *Clay infilling or slickensided* (Score = 81): Low friction material infilling such as clay separating joint surfaces and negating any roughness of the joint surface (slickensided joints have very low friction angles)

Slope angle: The slope angle is the angle between the horizontal plane and the mean plane of the slope face. The slope angle can be measured using different methods, such as: (1) field measurement using an inclinometer or Brunton pocket transit; (2) using photographs; or (3) by manual estimation. With experience, an observer can estimate the slope angle with precision. The slope angle is important because the failure potential increases with an increasing slope angle. For jointed rockmass, the friction angle ranges from greater than 45^o for very good quality rock to about 30^o for fair quality rock. Friction angles less than 30^o are possible for poor to very poor quality rock. The cohesion ranges from greater than 58 psi to about 36 psi for very good to fair quality rock. Very poor quality rock (i.e., soil-like) has a cohesion of less than 14 psi. Based on the friction and cohesion of the jointed rockmass, this category is scored as follows:

- Score = 3: A slope cut less than 1:1 (< 45^o) should maintain its stability.
- Score = 9: Slope cuts from 1:1 to ½:1 (45^o - 63^o) have a low failure potential.
- Score = 27: Slope cuts from ½:1 to ¼:1 (63^o - 76^o) have a moderate failure potential.
- Score = 81: Any rock slope with a cut angle from $^1/_4$:1 to vertical (> 76^o) is potentially unstable.

Maximum slope height: This category scores the potential hazard of slope height. Sliding/falling rock blocks on high slopes have greater potential energy than moving blocks on lower slopes. The higher the potential energy, the greater distance the block can travel, possibly reaching the roadway; thus, higher slopes represent greater hazards and receive higher ratings.

The maximum vertical height from the base of the slope to the highest point on the cut slope face should be measured. If, however, the sliding/falling rock block originates from the natural slope above the cut, the additional vertical height should be included in the measurement. The exception to this is if the sliding/falling rock comes from the natural slope above the cut, the additional vertical height to the launching point should be included in the measurement. Slope height can be measured using different methods: (1) using photographs; (2) by field estimation; (3) using trigonometric relationships in the field; or (4) using a sighting level and rangefinder. Slope height is divided into four sub-categories as shown in the table above.

Category Rating	3	9	27	81
Water Seepage/ Surface Drainage	Dry, no flow	Damp, no free water present	Dripping water	Continuous water flow

Water and freeze-thaw cycles contribute to the rockmass weathering and change the rockmass strength. Both of these climatic parameters are rated separately. Water seepage or water on soil slope surfaces is an indication of the degree of saturation in the soil mass. Water in cracks and joints in rock reduces the effective stress acting at the base of the sliding block. On occasion, it initiates slope movement by generating an additional horizontal water pressure. This category is determined by visual observations, where water is known to flow continuously or intermittently from the slope. The rating table above contains descriptions of the rating criteria.

Category Rating	3	9	27	81
Annual Freeze-Thaw Days	Less than 50 days	50 to 70 days	70 to 125 days	Greater than 125 days

The annual freeze-thaw days were established by reviewing the daily climatic data from 1971 to 2000. The National Climatic Data Center at NOAA divides the State of Alaska into nine regions. Each freeze-thaw day is defined as a 24-hour period during which the daily maximum temperature is above 32^{o}F and the daily minimum temperature dips below 32^{o}F. This data is used because of the long data collection period and wide distribution of weather stations across Alaska.

Because of large geographic regions with very different climatic patterns in Alaska, the observer needs to choose the annual freeze-thaw days closest to the slope site from the list below.

Annual Freeze-Thaw Days (Select a value closest to the slope site):

1) *Southeast:* Juneau (97 days); Ketchikan (102 days)
2) *Southcentral*: Kodiak (180 days); Valdez (78 days)
3) *Southwest*: Cold Bay (157 days)
4) *Copper River Valley*: Gulkana (84 days)
5) *Cook Inlet:* Anchorage airport (70 days); Homer (119 days): Talkeetna (90 days)
6) *Bristol Bay:* King Salmon (87 days)
7) *West Central:* Bethel (50 days); Nome (42 days)
8) *Interior*: Fairbanks airport (63 days); Big Delta (57 days); Cantwell: 88 days
9) *Arctic*: Barrow (35 days)

Based on the climatic data and the adverse effect of freeze-thaw cycles on rock strength, break points are identified, which provide a reasonable distribution of hazard ratings as summarized in the above table. This category also should be used for soil slopes and embankments. It is the general understanding that repeated freeze-thaw cycles decrease soil particle size and overall strength.

Category Rating		3	9	27	81
Slope Movement	Block size - - - - - - - - - - - volume per event	6-12 inches - - - - - - - - - - - - Less than 3 yd^3	1-2 ft - - - - - - - - - 3-6 yd^3	2-5 ft - - - - - - - - - - - - 6-12 yd^3	Greater than 5 ft - - - - - - - - - - - - - - - - - Greater than 12 yd^3

Block size affects the hazard potential since larger blocks have greater kinetic energy than smaller ones. This measurement should be representative of the dominant failure mechanism at the site. If individual rock blocks are typical of the slope failure, measure or estimate the maximum dimension of the largest rock block. If the unstable slope consists of soil, IGM, or debris, the volume of the sliding material per event should be estimated. It is best to obtain this information from the corresponding M&O station. If the data is unavailable, block size or volume per event can be based on visual assessments of the site. If the observer is uncertain about the type of failure, her or she should use the mode that gives the higher score. The rating table above contains descriptions of the rating criteria.

Category Rating			3	9	27	81
Slope Movement	√ one	Historical Activity	Once every 2 to 4 years	1 to 2 times a year	3 to 6 times a year	7 times a year or more
		Potential	Slope movement unlikely to happen	Slope movement unlikely to reach pavement	Slope movement possible, but with low frequency	Slope movement possible and with high frequency

This category scores the failure frequency of an unstable slope or the probability of future slope movement. The historical activity information represents known previous slope failures and cleanout activities at the site. Maintenance records are the best source of information. When neither records nor M&O personnel responsible for site cleanout are available, guidance is necessary for estimating the rockfall/landslide history. The amount of material in the ditch, number of impact marks on the pavement caused by rolling rocks, and the presence of rock/debris in the road are some of the indicators that can be used. On the Slope Hazard Rating form (Step 2), the frequency of rockfall or landslide activity is rated differently than on the Preliminary Slope Rating form (Step 1); the net effect is a conservative approach at the early stage of assessment process.

The evaluation of potential slope movement is subjective. However, with a detailed field survey of site geology and structure, climate and water condition, cut slope and natural slope geometry, the observer will have a better grasp of the slope site and can make a meaningful evaluation.

Initial Assessment Summary				
Preliminary (max 243)	Hazard (max 486-567)			**RISK (max 486)**
	S	E	R	

Recommended Action:	
Comments:	

Post-remediation Assessment				
	Hazard (max 486-567)			**RISK (max 486)**
	S	E	R	

Recommended Action:	
Comments:	

B.4 Slope Risk Assessment Form (Step 3)

The Slope Risk Assessment Form requires the observer to transfer the preliminary and hazard rating results to summary blocks at the top of the form. For the hazard assessment, the observer should identify the type of slope problem (i.e., S = soil slope; E = embankment; R = rock slope). The total risk is the sum of six risk categories discussed below. The maximum total risk is 486, and the minimum is 18. Recommended action should be made according to the policy set by the AKDOT&PF administration or a committee overseeing the Unstable Slope Asset Management system. Recommended action can include a wide range of activities from "no action" to "cost-benefit analysis" to "slope remediation." If an unstable slope is remediated, it should be re-assessed using the Slope Risk Assessment form. Post-remediation assessment scores are summarized in the second tier of blocks at the top of the form.

Category Rating →	3	9	27	81
Hazard Class (use the score from Hazard Rating form)	*Class I:* Soil and Rock ≤ 21 Emb. ≤ 18	*Class II:* 21 < Soil and Rock ≤ 63 18 < Emb. ≤ 54	*Class III:* 63 < Soil and Rock ≤ 189 54 < Emb. ≤ 162	*Class IV:* 189 < Soil and Rock ≤ 567 162 < Emb. ≤ 486

The rating of the Hazard Class needs to be transferred from the Slope Assessment Form. The Total Hazard Score varies depending on the type of slope: a rock or soil slope (R or S) may have a maximum rating of 567, and an embankment (E) may have a maximum score of 486. These ranges in ratings, however, do not indicate different levels of hazard severity. Instead, they stem from the different sets of criteria used in rating each type of failures. For example, there are seven criteria for rating a rock or soil slope hazard, and six criteria for an embankment. The Total Hazard Score is further divided into four hazard classes.

For soil and rock slopes:

- Class I hazard: Total Hazard Score ≤ 21
- Class II hazard: 21 < Total Hazard Score ≤ 63
- Class III hazard: 63 < Total Hazard Score ≤ 189
- Class IV hazard: 189 < Total Hazard Score ≤ 567

For embankment failures:

- Class I hazard: Total Hazard Score ≤ 18
- Class II hazard: 18 < Total Hazard Score ≤ 54
- Class III hazard: 54 < Total Hazard Score ≤ 162
- Class IV hazard: 162 < Total Hazard Score ≤ 486

Category Rating →	3	9	27	81
Impact on Traffic	Normal traffic continues	Two-way traffic continues with some delay	One lane remains open	All lanes are blocked; long detour required

This category rates the impedance of traffic due to a slope failure. Measurement of the impact on traffic involves several parameters such as the failure length of the unstable slope along the roadway, the width of the roadway impacted, the severity of damage to pavement, and the traversability of the unstable area. Based on field observation shortly after a slope failure, the observer should classify the impact on traffic as:

- No Impact (Score = 3): The pavement damage or road blockage by falling rocks or sliding soils/debris is none or almost not existent. Normal traffic continues at the posted speed limit.
- Moderate Impact (Score = 9): The pavement damage or road blockage by falling rocks or sliding soils/debris interrupts the traffic flow. Motorists must travel at a reduced speed.
- Severe Impact (Score = 27): The nearest lane of an undivided road is completely or nearly completely blocked. Motorists must stop before passing the failed area.
- Extreme Impact (Score = 81): Both lanes of an undivided road are completely blocked. The road is not traversable, and a detour is required.

Category Rating →	3	9	27	81
Annual Average Daily Traffic (AADT)	< 500	500 – 4,000	4,000 – 10,000	> 10,000

Annual Average Daily Traffic (AADT) is the average daily traffic volume passing by an unstable slope in a period of one year. The AADT is the combined traffic volume in both traveling directions for an undivided roadway. For a divided roadway, AADT is the traffic volume in the lane(s) adjacent to the slope.

A slope site with a high AADT suggests that a higher number of accidents or higher cost of traffic delay could occur due to slope-related hazards. The AADT also indicates the importance of a roadway. Closing the roadway for cleanout or remediation may affect the regional economy. The daily traffic volume data can be obtained from the AKDOT&PF regional office.

The rating of AADT for a combined two-way traffic volume is as follows:

- Score = 3: < 500 vehicles/day
- Score = 9: 500 – 4,000 vehicles/day
- Score = 27: 4,000 -10,000 vehicles/day
- Score = 81: >10,000 vehicles/day

Category Rating →	3	9	27	81
Average Vehicle Risk (AVR)	< 25%	25% - 50%	50% - 75%	> 75%

The average vehicle risk (AVR) is the percentage of time that a vehicle is present in the unstable slope zone. The percentage is obtained using a formula based on slope length, AADT, number of lanes, and the posted speed limit through the hazard zone. A rating of 100% implies that on average one vehicle can be expected to pass the hazard zone. A rating higher than 100% means that at any given time more than one vehicle is present within the hazard zone. Once the AVR is calculated, a discrete value is assigned based on the above table. The equation used to calculate AVR is:

$$AVR,\% = \frac{AADT * L}{s * 24} * 100\%$$

Where *AADT* is average daily traffic (vehicles per day), *L* is the length of unstable slope zone (miles), and *s* is the posted speed limit (mi/hr). The 24 converts days to hours.

Category Rating →	3	9	27	81
% Decision Sight Distance (PDSD)	Adequate (100%)	Moderate (80-99%)	Limited (60-79%)	Very Limited (< 60%)

The percent decision sight distance (PDSD) is the maximum road length that a driver has to identify and avoid a rockfall hazard. The PDSD is critical when obstacles on the road are difficult to perceive, or when unexpected or unusual maneuvers are required. The actual DSD is measured along the edge of pavement in the direction of oncoming traffic. It is the distance from the edge of a hazard zone to where a 6 in. object disappears when viewing the road at a height of 3.5 ft above the ground. The distance is measured in both directions, where both directions of traffic are likely to be affected, and the shorter distance is recorded. The recommended AASHTO Decision Sight Distances are:

Posted Speed (mph)	Decision Sight Distance (ft)
30	450
40	600
50	750
60	1,000
70	1,100

The Percent of Decision Sight distance (PDSD) is determined using the following formula:

$$PDSD,\% = \frac{ASD}{DSD} * 100\%$$

where *ASD* is the actual sight distance (ft) and *DSD* is the decision sight distance (ft).

Category Rating →	3	9	27	81
Maintenance Response:	Once every 5 years or less	Once every 2 to 4 years	1 to 2 times a year	3 times a year or more
Frequency or Cost	< $2,000	$2,000-$5,000	$5,000-$25,000	> $25,000

The economic impact of a slope failure is easy to evaluate because delay of traffic or detouring can have far-reaching effects to the surrounding communities. Rather than directly determining the economic impacts, indicators of the impacts can be used. Two most reliable indicators are the costs associated with traffic delays and the annual maintenance costs over a 20-year span. A cost-benefit analysis can be made based on the costs of traffic delays and life-cycle maintenance (i.e. 20 years), and the cost to permanently repair the unstable slope. At the present time, AKDOT&PF does not have the complete records to conduct an economic analysis. However, as the database of the 20-year maintenance costs is established, the economic component of the unstable slope asset management system can be improved.

The observer rates this category in terms of the annual maintenance frequency or maintenance cost, whichever data is available.