CHAPTER 7 – ROCKFALL MITIGATION SELECTION

Selecting effective rock slope stabilization and rockfall protection measures (collectively referred to as rockfall mitigation) is critical for protecting the public and structures from falling rock. Population growth, past practices, and the deterioration of older constructed rock slopes has brought more attention to the need to mitigate existing rockfall hazards. In addition, there are many naturally occurring rockfall areas that have become hazardous because of the presence of roads or structures.

CONSIDERATIONS

Mitigation selection should be based on several things:

- The degree of security or reliability necessary for a site.
- The constructability of the potential options.
- The service life required.
- The suitability of potential mitigation options with respect to the characteristics of the specific rock mass.
- Aesthetics.
- The cost effectiveness.

Security/Reliability

The reliability of rockfall mitigation is related to the potential or probability for damage or harm in the event of a rockfall. The likelihood of a rockfall event causing immitigable damage would determine the degree of increased security or level of hazard reduction. If the prospects of a rock falling do not potentially cause a hazard or damage, then it is likely that mitigation is unnecessary.

Constructability

The constructability of the mitigation plays a large role in its selection, and there are many facets to this issue. For example, many sites along highways have unique space and right-of-way characteristics. In these cases, typical issues may include the difficulty of installing a wide, double-sided, mechanically stabilized earth (MSE) barrier, trimming and scaling of rocks located above residences, or limited access to slopes for installing reinforcement or netting.

Service Life

The duration that rockfall mitigation is expected to be effective for (service life), can be related to how fast the rock erodes and how fractured the rock is, as well as the most economical type of mitigation for the site. For example, rock bolts placed in highly fractured shale may last only three to five years and mitigate only large blocks. Maintenance costs on these bolts would be expected to be high, and the rock face would probably need additional reinforcement on a regular basis, but that cost might still be lower than reshaping the slope. However, if a client prefers a long-term, low-maintenance solution, then a different mitigation solution would be selected.

Suitability

The suitability of rockfall mitigation is determined by several factors, and should be determined based on a thorough analysis of the rockfall hazard and slope characteristics, which include the presence of weak materials, discontinuities adverse to the slope strike and angle, block size, and the presence of tension cracks and/or groundwater. The site should also be evaluated to determine the potential effects of rockfall and the desired effects of the selected mitigation.

Aesthetics

Another consideration in rockfall mitigation selection is the aesthetic effect of the mitigation method, as well as its potential impact on the natural scenery and historic setting and any native wildlife. When developing mitigation alternatives, the measures should be constructed in such a way as to minimize impacts to the setting while also reducing the potential rockfall hazard.

Cost Effectiveness

The effectiveness of mitigation relative to the initial and maintenance costs plays as substantial role in its selection. More often than not, cost is the primary factor in selecting the type of rockfall mitigation. Cost effectiveness can be difficult to measure in advance of installation and is related to the probability of how much of the potential significant damage will be mitigated.

COMPARISON OF MITIGATION METHODS

Table 12 shows a qualitative comparison of different stabilization and protection measures. This table is intended to be used as a quick reference. Roadway layout and rock characteristics will have a large influence on each of the criteria and may alter the range of values for each.

MAINTENANCE CONCERNS

Following construction, maintenance personnel should perform daily patrols of rockfall-prone areas to keep the travel way clear of hazardous debris. Patrol frequency can range from a few times per shift during low-frequency periods to 24 hours per day, seven days a week during high-rockfall periods. Seasonal occurrences of freeze/thaw or heavy precipitation as well as wild fires and other events, all can increase rockfall potential.

Managing Rockfall Incidents

Documentation

Rockfall events should be documented to establish areas of increased rockfall activity and help with future mitigation selection and design. Information that should be included in the rockfall documentation includes:

- date and location of rockfall event (including a mile marker or other location description);
- size and number of rocks involved;
- rockfall source area, if known;
- rockfall stopping point in relation to the travel corridor; and
- possible triggering mechanism(s).

Table 12. Properties of different rockfall and slope stability mitigation measures.

MITIGATION MEASURE	CRITERIA							
	Complexity	Effectiveness	Durability	Constructability/ Special Expertise	Road Closure/ Traffic Restrictions	Aesthetic Impacts	Cost	Maintenance Requirements
STABILIZATION METHODS								
Excavation								
Hand/Mechanical Scaling	L-M	L-H	L-M	M	Y	L	L-M	L-M
Trim Blasting	L-H	L-H	M-H	L-H	Y	L-H	L-H	L-M
Reinforcement								
Rock Bolts	M-H	M-H	H	H	P	L	M-H	L
Dowels	M	M-H	H	H	P	L	M-H	L
Shear Pins	M	M	M	M	P	M	M	L
Shotcrete	M-H	M-H	M-H	H	P	M-H	M-H	L
Injectable Resin/Epoxy	M-H	M-H	M-H	H	P	L	M-H	L
Wire Mesh (anchored)	M	M	M	M	P	H	L-H	M-H
Drainage								
Weep Drains	L	L-H	M	L	P	L	L	H
PROTECTION METHODS								
Mesh/Cable Nets								
Draped Mesh	L-M	M-H	M-H	M	Y	M-H	L	L-H
Suspended Systems	L-M	M-H	M-H	M	Y	M-H	L-M	L-M
Barriers and Fences								
Earthen Berms	L	M-H	H	L	P	L-M	L	M-H
Concrete Barriers	L	M	L-M	L	P	M-H	L	M-H
Structural Walls	L-M	M-H	M	M	P	M	L-M	M-H
Fencing	M-H	M-H	M-H	M	Y	M-H	M	M-H
Attenuators	M-H	M-H	M-H	M	Y	M-H	M	M
Ditches								
Ritchie/ODOT	L	M-H	H	L	P	L-M	L-H	H

L = low, M = medium, H = high, VH = very high, N = no, Y = yes, P = possibly

Action Plan

In all areas where rockfall occurs, a maintenance team should have a set action plan in case of a large rockfall event. In high-risk areas, the plan must be well defined and routinely practiced by maintenance personnel. The action plan should include:

- roles and responsibilities of early responders;
- contact information for emergency and traffic control personnel;
- site-assessment procedure for qualified personnel, including slope stability evaluation and possible remedial measures; and
- location and/or procurement procedures for all machinery required for rockfall removal.

Maintenance Procedures

All cut slopes and their attendant stabilization and protection systems must be monitored for damage, weathering, stability, and rock accumulation. Periodic maintenance will be needed to uphold safety. In previous chapters, maintenance issues and possible rockfall-induced damage were discussed with each mitigation method covered. Table 13 summarizes common maintenance procedures for each of these measures.

Table 13. Maintenance procedures for mitigation measures.

MAINTAINED ITEM	MAINTENANCE PROCEDURE
STABILIZATION MEASURES	
Cut Slope	Periodic scaling (every 2 to 10 years) to remove loosened and/or unstable material.
Rock Bolts	Check to ensure hex nuts and bearing plates are flush with rock face. Tighten any loosened hex nuts to appropriate load.
Rock Dowels	If bolt extends from slope face, end may be cut for aesthetics. If grout adhesion has failed or slope surface has eroded (i.e., slope extends past dowel end), conduct stability analysis on slope.
Shear Pins	Ensure bending or shearing of pins has not occurred from block movement. If it has, shear pins may need to be re-installed or block removed.
Shotcrete	If shotcrete is cracked or separated from rock face, remove and reapply. Clear any drains that are plugged or blocked with obstructions.
Injectable Resin/Epoxy	Maintenance of resin/epoxy is not needed after injection. If rockfall or stability problems persist after injection, additional stabilization or protection measures may be needed.
Wire Mesh (Anchored)	Remove any accumulated material suspended in mesh or at slope base. If mesh is damaged, repair or replace damaged section(s).
Weep Drains	Clear drains periodically; remove any obstructions.
PROTECTION MEASURES	
Draped Mesh/Suspended Mesh	Remove any accumulated material suspended in mesh or at slope base. If mesh is damaged, repair or replace damaged section(s).
Earthen Berms	Clear accumulated material periodically. Repair any damaged section(s) of berm.
Concrete Barriers	Clear accumulated material periodically. Replace any damaged section(s) of barrier.
Structural Walls	Clear accumulated material periodically. Repair damaged section(s) of wall.
Fencing/Hybrid Fencing	Clear accumulated material. Check fence, cables, braking devices, and posts for damage and repair/replace any damaged part(s).
Ditches	Clear accumulated material periodically.