

## **ROCKFALL REMEDIATION**

### **Scaling**

#### Description and Purpose:

- Loose rocks and debris are removed from slopes through hand removal (using rope access), mechanical (using a long arm backhoe or jackhammer), explosive, and/or expansive chemical procedures.
- By removing potential projectile hazards, the likelihood that a rockfall will occur is reduced.
- Scaling is conducted from the top of the slope down.

#### Applications:

- Used along and above cut slopes or natural slopes near roadways.
- Usually the first remedial measure applied to a slope with a high hazard Level.
- Can be conducted during the construction of a new roadway, or as a regular maintenance procedure.

#### Advantages:

- Can be completed as a standalone remedial measure, or used in combination with other options.
- Is often all that is required to reduce the hazard level.
- Does not implement infrastructure that could require maintenance.
- Does not affect the aesthetics of the slope.

#### Limitations:

- Requires skilled slope workers for safety purposes.
- Requires traffic control since debris slides and rockfalls are generated during the process.
- Mechanical or explosive operations can create additional rockfall hazards due to vibrations.
- Temporary measure since additional rocks can become dislodged with time.

## **Rock Bolts**

### Description and Purpose:

- Rock bolts are steel rods that are installed into holes drilled in the rock.
- The rods are anchored into the rock by a variety of mechanical means, and a faceplate and nut are installed against face of the rock.
- The bolts are generally grouted into place after installation, and can be tensioned, if required.
- When installed alone or in a pattern, can hold the outer surface of the slope together reducing the rock's ability to loosen and unravel.

### Applications:

- Permanent measure.
- Used along cut or natural slopes adjacent to highways.

### Advantages:

- Provides support to the outer surface of rocks.
- Does not require slope excavation.
- Can be completed as a standalone remedial measure, or can be combined with other options.
- Requires minimal maintenance.

### Limitations:

- Requires skilled slope workers for safety purposes.
- Are not applicable for use on talus slopes (i.e. slopes comprised primarily of debris).
- Numerous bolts installed in a close pattern may be required if used as a stand-alone remedial measure.

## **Shotcretes**

### Description and Purpose:

- Shotcrete is a generic term for cement, sand, and fine aggregate concretes which are applied pneumatically and compacted dynamically under high velocity.
- Shotcrete is sprayed onto the rock slope using steel mesh or steel fibers for reinforcement.
- Is usually applied in conjunction with rock bolts, and the shotcrete surface restrains portions of the slope between the bolts themselves.

### Applications:

- Permanent measure.
- Used along steep cut or natural slopes adjacent to highways.
- Primarily used in conjunction with rock bolts.

### Advantages:

- Is especially effective when used as a supplemental restraint measure with rock bolts for highly fractured slope faces.
- Does not require slope excavation.

### Limitations:

- Requires geotechnical input to determine thickness and reinforcement requirements.
- Care has to be taken to allow for groundwater drainage when applying shotcrete to a slope, since the shotcrete will block any natural drainage.
- Is not normally a stand-alone remediation measure.
- Can be weathered with time.

## **Berms**

### Description and Purpose:

- Berms are permanently excavated into the rock slope.
- The berms reduce the energy of the falling projectile by trapping or slowing rockfalls.
- Berm geometries are dependent on the site-specific slope geometry and expected projectile size, and as such, require a detailed rockfall simulation to design; however, benches of greater than 6 m wide should be considered in preliminary planning to provide access for removal of debris.
- Gravel layers are typically placed on each bench to further reduce the projectile's energy to optimize the effectiveness of the berms.

### Applications:

- Permanent measure.
- Used along cut or natural slopes adjacent to highways.

### Advantages:

- When properly maintained (to keep debris from piling up on benches), are effective at reducing the number, and limiting the energy, of rockfall hazards.
- Can be used as a stand-alone remedial measure, or used in conjunction with other methods.

### Limitations:

- Depending on the geometry of the original slope, can require significant excavation to implement.
- Requires a detailed rockfall analysis to properly design bench heights and widths.
- Requires regular maintenance to remove accumulated debris on the benches.
- May result in inferior traffic benefits as compared to widening a cut, particularly in the form of increased horizontal sight distance on curves.

## Ditches

### Description and Purpose:

- Ditches are a type of rock trap established at the toe of the slope to catch rockfalls prior to impacting the roadway.
- Can be used where sufficient room is available between toe of the slope and the roadway.
- For preliminary design purposes, the geometric requirements in the following table can be used for the ditch (B.C. Ministry of Transportation and Highways, 2002).

Rock Cut Heights (m)	Catchment Width (m)	Catchment Depth (m)
0 to 8	3	0.75
8 to 16	4	1
> 16	5	1.25

- Slope stabilization/remediation measures are required in conjunction with ditches for slopes heights above 10 m.
- Gravel layers are typically placed in the ditch to further reduce the energy of projectile.

### Applications:

- Permanent Measure.
- Used at bottom of cut or natural slopes to collect rockfalls.
- Can be used as a standalone remedial measure or in conjunction with other methods.

### Advantages:

- Can be completed as a stand-alone remedial measure, or can be combined with other options.
- Can result in traffic benefits when widening cut, particularly due to increased horizontal sight distance on curves (WSDOT, 2008).

### Limitations:

- Can only practically trap rockfalls of a certain size or energy, so often requires additional rockfall remediation measures.
- Can not contain rockfalls that fall directly onto the roadway.
- Requires a detailed geotechnical analysis using probabilistic methods to determine the detailed ditch geometry.
- Requires regular maintenance to maintain the ditch free of rockfall debris accumulation.

## **Barriers**

### Description and Purpose

- Barriers are a type of rock trap established adjacent to a highway at the toe of the slope to impede rockfalls from travelling onto the roadway.
- Are also used in conjunction with ditches where sufficient room is not available to “capture” the anticipated rockfalls, to increase the capacity of the ditch, or to impede higher energy projectiles from encroaching on the road.
- Can include general earth embankments; jersey barriers; concrete walls; gabion baskets; guardrail with barrier nets attached to the backside; a high rigid wall usually consisting of two rows of lock blocks perhaps three metres apart, with soil infilled between them and the entire mass reinforced with geogrid.

### Applications:

- Permanent or temporary measure.
- Used adjacent to roadways at bottom of cut or natural slopes.
- Primarily used in conjunction with ditches and other remedial measures.

### Advantages:

- Can be low cost and modular.
- Can significantly increase the effectiveness of other remedial measures; in particular, ditches.

### Limitations:

- Of limited use as a stand-alone measure.
- Can not contain rockfalls that fall directly onto the roadway.
- Requires a detailed geotechnical analysis using probabilistic methods to determine the likely rockfall size to be contained.
- May not be as effective if installed in wrong location.
- Requires regular maintenance to maintain the up-slope side of the barrier free of rockfall debris.
- May have highway maintenance issues, e.g., luring snow drafting and resulting in difficult snow plowing timely.

## **Catch Fence**

### Description and Purpose:

- Catch Fences are a type of rock trap established adjacent to a highway or along a slope to impede rockfalls from travelling onto the roadway.
- Some fences can use energy absorbing rings to reduce the velocity of the boulders, whereas other fences plastically deform when the projectile makes impact.
- Can be installed in one of three locations: roadway shoulder primarily used when small boulders or cobbles are expected; bottom of back slope; and upper back slope.

### Applications:

- Temporary or permanent measure.
- Can be used in conjunction with ditches and other remedial measures.

### Advantages:

- Can be low cost and modular.
- Effective at restraining large boulders.
- Can significantly increase the effectiveness of other remedial measures; in particular, ditches.

### Limitations:

- Can not contain rockfalls that fall directly onto the roadway.
- Requires a detailed geotechnical analysis using probabilistic methods to determine the likely rockfall size to be contained.
- May not be effective if installed in wrong location.
- Requires regular maintenance to maintain structural integrity of the fence, as well as to keep the up-slope side of the fence free of rockfall debris.

## **Mesh Draping**

### Description and Purpose:

- When attached periodically along the rock mass, mesh draping can control the trajectory of the rockfall.
- The objective of the mesh is to trap the falling rocks near the slope face rather than to restrain rockfalls from occurring.
- By trapping the falling rocks, the energy of the projectile is reduced by causing the rock to roll or tumble, rather than bounce.

### Applications:

- Temporary or permanent measure.
- Especially useful on steep cut slopes.
- Used in conjunction with ditches and other remedial measures.

### Advantages:

- Low cost and modular.
- Guides the rockfalls towards other remedial measures.
- Helps contain rocks from falling directly on roadway.
- Can reduce the energy of a rockfall, thereby reducing the structural requirements of other remedial measures.

### Limitations:

- Not normally applied as a stand-alone remedial measure.
- Requires periodic maintenance to maintain structural integrity of the mesh.
- May have environmental concerns (e.g., trapping wild animals) and aesthetics.



## **Rock Shed (Avalanche Shelter)**

### Description and Purpose:

- Structure installed over the roadway to withstand rockfalls.
- Primarily comprised of reinforced concrete.
- Typically have a sloped roof and gravel or soil cap to retard and deflect rockfalls.

### Applications:

- Permanent measure.
- Used on steep slopes, primarily above narrow roadways.

### Advantages:

- Complete reduction in rockfall hazards over the length of roadway encompassed by the rock shed.
- Effective where additional space is not available adjacent to the slope for other measures.

### Limitations:

- Requires significant detailed design effort.
- Cost restrictive over large areas.
- Requires more robust design for wider roads.
- Have traffic considerations due to transition to and from natural light.
- Requires long term maintenance.