CHAPTER 15

ROCK SLOPE DESIGN
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15.1 OVERVIEW

This chapter discusses stability analysis, excavation guidelines, and stabilization techniques for rock slopes adjacent to highways, including planning for excavation, rock catchment, and rock mass improvement techniques such as bolting, dowelling, shotcreting, etc.

15.1.1 History and Background

New York State contains a variety of rock types, dating in age from Precambrian to Upper Triassic, which have experienced tectonic stresses ranging from mild to severe. This geologic background has resulted in rock that can have variable stability, depending on location, rock type, and rock structure. Prior to World War II, all rock cut slopes were designed as 4 vertical on 1 horizontal (4V on 1H, 76°). This universal template was modified during the construction of the Interstate Highway System as empirical experience showed that flatter angles of rock cut design were more stable depending on rock type and structure. Improvements in rock cut construction also resulted from changes in rock blasting techniques, many of which were pioneered during rock excavation projects on the Interstate Highways in New York.

15.2 NYS DOT ROCK SLOPE DESIGN POLICY

The Engineering Geology Section of the Geotechnical Engineering Bureau establishes the Departmental standards for the design of rock slopes and/or catchment areas, and provides guidance to the Departmental Geotechnical Engineers during the design and construction process. Engineering Geologists endeavor to ensure that rock slopes are constructed safely and economically and will optimize safety for the public. NYSDOT rock slope design policy encompasses four categories related to rock slope stability:

- Rock Slope Design
- Rock Catchment Area Requirements
- Rock Slope Stabilization and Rockfall Mitigation Techniques
- Rock Slope Rating System and Rockfall Database

15.2.1 Rock Slope Design

When a rock slope is created by an excavation required by a new alignment, a realignment of an existing road, or when a rock slope is addressed for safety reasons, the parameters of the rock will be discussed by the Project Designers with the Engineering Geologists. Cross sections of the cut area, from conventional survey, DTM, or LiDAR, will be provided, as well as any constraints posed by right of way limitations, utility corridors, or environmental restrictions. The Engineering Geologist will design the rock cut slope that satisfies the various needs of the project, and that is the steepest configuration that is also stable given the local geology. The rock slope design will also include the rock catchment area recommendations that are appropriate for the height and inclination of the slope face, as described in Section 15.2.2 Rockfall Catchment Areas.
The detailed requirements for the design of rock cuts are provided in FHWA-HI-99-007, *Rock Slopes Reference Manual*, publication dated 1998. In addition, the Geotechnical Engineering Bureau’s *Procedures for Blasting* (GEM-22), serves as the basis for all regulations and recommended practices regarding blasting for rock cut excavation.

The purpose of the rock slope design process is to design and construct rock cuts that will be stable and provide long-term safety for the public. The inclination of rock slopes should be based on the structural geology and stability of the rock units. Rock slopes of vertical, 3V on 1H, 2V on 1H, 3V on 2H and 1V on 1H are used at NYSDOT. The design rock cut slope should be the steepest continuous slope that satisfies the constraints of the project site and stability considerations.

The inclination of rock slopes should be based on the structural geology and stability of the rock units. Rock slopes of vertical, 3V on 1H, 2V on 1H, 3V on 2H and 1V on 1H are used at NYSDOT. The design rock cut slope should be the steepest continuous slope that satisfies the constraints of the project site and stability considerations. As required by §203-3.02.A. *Rock Excavation* of the NYSDOT Standard Specifications, presplit blasting is required for rock cut slopes 1V on 1H or steeper that are greater than 5 ft. in height. The purpose of using this controlled blasting method is to minimize blast damage to the rock face and backslope to help insure long-term stability, improve safety, and lessen maintenance.

In general, 3V on 1H slopes are used for granitic gneisses of the Adirondacks and hard, sound Devonian limestones, and dolomites. 2V on 1H slopes and 3V on 2H slopes are used for sandstones of the Southern Tier and the Catskills. Most rock cuts in the lower Hudson Valley are cut on 3V on 2H, because the history of tectonic deformation in that area affects the stability of the rock. All shale slopes are cut on 1V on 1H angles. These angles of slope inclination may be modified based on structure, degree of deformation and/or induration, susceptibility to weathering, and other factors, as determined by the Engineering Geologist.

15.2.2 Rockfall Catchment Areas

A rockfall catchment area is defined as the area between the roadway edge of pavement and the base of a cut slope, used to restrict rockfalls from the roadway (Pierson et al., 2001). The term catchment area is synonymous with ditch, rockfall ditch, rockfall catch ditch, and rock fallout area. In highway design, the width of the rockfall catchment area is measured as the horizontal distance between the edge of the roadway pavement and the base (toe) of the rock slope, and its depth is the vertical distance between those two features. Rockfall catchment areas were first researched by Ritchie (1963), based on his empirical studies which involved rolling rocks off slopes in Washington State. Later, more extensive research was done in Oregon in a pooled fund study, based on more rolling rock studies on a greater number of different slope configurations.
15.2.2.1 Ritchie Ditch Catchment Area

Adequately designed rock catchment ditches will prevent most falling rock from reaching the road. Ritchie Ditch profiles are based upon the pioneering work of Arthur M. Ritchie, who conducted a study in 1963 sponsored by the US Department of Commerce, Bureau of Public Roads and the Washington State Highway Commission. The study produced a set of practical design criteria that could be used to size the width and depth of catchment area based on slope height and slope angle. The resulting ditch is flat bottomed and has a 1 V on 1 1/4 H foreslope. The steep foreslope is difficult to construct and maintain using typical construction methods and materials, and is deemed a non-recoverable slope which poses a hazard and must be protected using guide rail. When compared to other current rock catchment design methods, Ritchie Ditch profiles cover the widest range of slope heights and slope face angles, and are designed to achieve 85% rockfall catchment.

Figure 15-1 Ritchie Ditch Criteria – Ditch Design Chart
(FHWA Rock Slopes, May 1988)
Figure 15-2 Ritchie Ditch Criteria – Rock Falls on Slopes
(FHWA Rock Slopes, May 1988)

Figure 15-3 Typical Ritchie Ditch Section
15.2.2.2 Oregon Catchment Area

To expand on the Ritchie Ditch criteria, the Oregon DOT conducted an extensive research project, final report issued 2002, through a pooled fund effort funded by several State Transportation Departments, including NYSDOT, and the FHWA. The research project had three main goals:

1. Investigate how slope, catchment area and rockfall properties affect retention at the base of vertical, 4V:1H, 2V:1H, 1.33V:1H, and 1V:1H slopes; for slope heights of 40 ft. (15.2 m), 60 ft. (18.3 m), and 80 ft. (24.4 m); and catchment area slopes of flat-bottom, 1V:6H and 1V:4H.

2. Develop improved guidelines.

3. Provide flexibility in designing catchment areas that will retain percentages of rockfall ranging from 30% to 99%.

The Oregon Ditch design guide uses catchment area slopes that are considered recoverable for errant vehicles. However, only a limited number of rock slope heights were considered in the study. For slopes that do not fall within these height criteria, or that will be cut at an angle different from those used in the Oregon study, interpolation of the ditch dimensions using Ritchie, Oregon, and the Colorado Rockfall Simulation Program (CRSP – See Section 15.2.2.3 Colorado Rockfall Simulation Program) can be used to design the rockfall catchment area for a rock cut slope.

![Typical Oregon Ditch Section](image)

**Figure 15-4 Typical Oregon Ditch Section**
15.2.2.3 Colorado Rockfall Simulation Program (CRSP)

A third method of rock catchment design is the computer program Colorado Rockfall Simulation Program (CRSP), which simulates rocks tumbling down a slope, predicts the statistical distribution of speed and bounce height, and can be used for locating and designing rockfall mitigation or rock catchment areas, and also the prediction of kinetic energy of falling rock. Only Engineering Geologists experienced in using these programs should perform the analysis.

When providing ditch widths, the recommended width may have to be wider than what would be required for adequate catchment to allow for 5 ft. (1.5 m) of burden for presplit blasting (See Section 15.2.3 Rock Slope Excavation/Construction).

15.2.3 Rock Slope Excavation/ Construction

Rock slopes designed at an angle of 1V on 1H or steeper that are greater than 5 ft. in height are required to be excavated by presplit blasting in accordance with the NYSDOT Standard Specifications. Slopes that are flatter than 45°, or less than 5 ft. in height, may be excavated by other blasting techniques, or by mechanical means of rock excavation.

The Geotechnical Engineering Bureau’s Procedures for Blasting (GEM-22) gives a detailed procedure for the preparation of rock blasting on NYSDOT projects, including licensing requirements for the blasters, requirements for submitting a blast plan prior to blasting work, and the scheduling of mandatory preblast meetings. By following this procedure, NYSDOT can help ensure that the Contractor accomplishes the work in a safe and effective manner. All blasting performed on NYSDOT must conform to Federal safety regulations as well as New York State Department of Labor licensing and safety statutes, and, depending on location, may be required to conform to local regulations as well.

Blasters in New York State are required to posses a valid New York State Department of Labor (NYSDOL) issued Blaster Certificate of Competence. The Blaster Certificate of Competence permits the licensee the use of explosives. In conjunction with a Blaster Certificate of Competence an Explosives License is also needed for the licensee to purchase, own, possess, or transport explosives.

As required by §107-05 Safety and Health Regulations, paragraph N, Drilling and Blasting of the NYSDOT Standard Specifications, a written blast plan prepared by a Project Blaster shall be submitted by the Contractor to the Engineer, in accordance with Procedures for Blasting (GEM-22), prior to scheduling a Preblast meeting. The blast plan shall detail the methods and manner by which the Project Blaster will comply with pertinent laws, rules, regulations, and contract documents. The plan shall include all information necessary to evaluate the effectiveness of the proposed blasting operations. The blast plan shall included all steps necessary to ensure that the proposed blasting activity does not cause injury, damage property, adversely affect traffic, or cause the migration and accumulation of noxious gases.
After initial review of the blast plan by the Engineering Geology Section of the Geotechnical Engineering Bureau and approval by the Engineer, a preblast meeting shall be held at the site to discuss the proposed blasting operations. A preblast meeting is intended to initiate open communications with the Project Blaster(s) relating to the requirements for rock drilling and blasting, and demolition by blasting work on NYSDOT projects. An Engineering Geologist from the Geotechnical Engineering Bureau conducts the Preblast meeting, which includes discussions on the blast plan and other pertinent information related to safety and communication on the project site. Final approval to blast will be granted by the Engineer after consultation with the Engineering Geology Section of the Geotechnical Engineering Bureau regarding the results of the meeting.

As required by §203-3.02.A.1, Presplitting of the NYSDOT Standard Specifications, the overburden shall be completely removed to expose the rock surface along the presplit line. This preparation of the shot area is required so the backslope can be adjusted to meet the design template in case the rock elevation is not uniform.

The term “burden” represents the volume of material that a detonating hole or holes are expected to fragment and shift. Drilled burden (measured perpendicular to the row of holes) is the:

- distance between a row of holes and the nearest free face, and is also the
- distance between two rows of holes.

Irregularities in the outer face of the slope can limit burden. For safe and effective presplit blasting, there must be a minimum burden cover of 5 ft. of rock or 10 ft. of soil on all sides of the presplit holes.

Following the blast plan to effectively detonate and remove the rock in a safe, efficient, and effective manner may require constructability phases to control the movement of rock during the blast (including size of shots and width of temporary benches) or operational measures (including blast mats, pavement protection, or a temporary rock catchment fence). A temporary rock catchment fence protects live traffic from unstable rock immediately after the blast and during mucking-out operations. The fence will also stop rock from moderately- to well-controlled blasts. Poorly-controlled blasts can damage a temporary rock catchment fence and can cause difficulties during the mucking-out operations.

Construction of rock slopes near highways frequently must consider traffic control during blasting and scaling operations. The traffic control may include adjacent railroad facilities where trains are running next to the highway or other adjacent structures and facilities. The cost of traffic control for a busy highway can potentially result in a doubling of the project cost. Therefore, careful consideration of staging, detours, work zones and blast-produced flyrock control must be done during design.
15.2.3.1 Lifts

As required by §203-3.02.A.1, Presplitting of the NYSDOT Standard Specifications, drill holes for presplitting shall be drilled at the designed slope inclination for a maximum slope face (not vertical) distance of 60 ft. As allowed by NYSDOT Standard Specifications, when excavation operations are conducted in multiple lifts, the presplitting holes for successive lifts may be offset a distance of not more than 3 ft. for a design slope of 1V on 1H and not more than 1 ft. for slopes of steeper design. The Contractor shall control the presplit drilling operations by using proper equipment and technique to achieve the design slope and maximum allowed bench between lifts.

15.3 ROCK SLOPE STABILIZATION AND ROCKFALL MITIGATION TECHNIQUES

Rock slopes that are at risk of producing hazardous rockfalls are best addressed by recutting to a more stable angle with adequate setback and catchment, as described in Section 15.2 NYSDOT Rock Slope Design Policy. However, it may not be feasible to recut potentially unstable slopes, for reasons of environmental impact, cost, right-of-way, etc. These rock slopes may require specific techniques developed to address situations where a hazardous rock slope situation may exist, in order to control a rockfall within a designated rockfall catchment area. A rockfall is the movement of a piece of rock from a slope that is so steep the rock continues to move down slope. The movement may be by free falling, bouncing, rolling or sliding.

Rock slope stabilization techniques are utilized to address specific geologic features which may lead to rock slope instability. Stabilization techniques include scaling, rock bolts and dowels, wire mesh and cable net slope protection systems, reinforced shotcrete, and trim blasting. Specific stabilization techniques with appropriate design will be recommended by the Engineering Geology Section as necessary.

15.3.1 Rock Slope Stability Analysis

Slope stability analysis for rock slopes involves a thorough understanding of the structural geology and rock mechanics. For most rock cuts, the stresses in the rock are much less than the rock strength so there is little concern with the fracturing of the intact rock. Therefore, stability is concerned with the stability of rock blocks formed by the discontinuities. Rockfall mitigation design heavily relies upon mapping of discontinuities to assess fracture and joint patterns and conditions, since the type and frequency of discontinuities will strongly affect the overall rock slope's stability. In some cases, test hole data should also be obtained, especially if surface mapping is not feasible due to the presence of overburden soil or for other reasons. Assessment of ground water present in the rock discontinuities, as is true of any slope, is critical to the assessment of stability.

Field data collection of the dip, dip direction, nature and type of joint infilling, joint roughness and spacing are important for the stability analysis of planar, wedge and toppling failure modes. Slope height, angle, presence of potential rock launching features, block size, and block shape are important for the analysis and design of rockfall mitigation techniques. Hand-calculation methods can be used to analyze potential planar and wedge failures and computer programs such
as ROCKPACK are also available. Refer to FHWA-HI-99-007, Rock Slopes Reference Manual (1998) for details on mitigation of rockfall and stabilization of rock slopes.

For rockfall mitigation measures, simulation of rockfalls using the CRSP computer program may be needed to determine the minimum required dimensions of a rockfall catch ditch and the kinetic energy of rocks that may need to be restrained by barriers, wire mesh, screens or walls. As a rule of thumb, draped gabion wire mesh slope protection and screens are capable of withstanding impacts from rocks up to 2 ft. in diameter. For larger rocks, rockfall fences or net systems or retaining walls will likely be needed. Experience indicates that rockfall catch areas wider than 30 to 35 ft. are not typically cost effective to construct, and additional barriers, fences or walls to gain ditch depth become more cost effective than wider ditches.

When rockfall mitigation designs are underway, concerns regarding construction, local environmental needs, and possible visual impact must be considered. Once resolved, the development and implementation of the geologic design can then be completed.

15.3.2 Scaling of Rock Slopes and Removal of Spoil

Rock slope scaling is one of the most effective methods of rockfall mitigation because it removes unstable rock before it can fall. Scaling of rock slopes can be done with blasting (Item 203.33030017) or without blasting (Item 203.33120017). Rock slope scaling is the removal of loose overhangs, weathered pockets, or unconnected rock from the slope. Scaling operations proceed either manually (with hand tools), or by a mechanical device designed to catch onto and pull loose rock and other debris from the slope. In addition, rock and debris which cannot be removed by manual or mechanical means but constitutes a potential problem may be removed by drilling and blasting.

The specification for scaling requires a Special Note for the conversion of weight to volume along with an estimated quantity of material to be removed. This Special Note contained sections for the Designer to fill-in with the unit weight of the site specific material provided by an Engineering Geologist.

The following formula, based on a unit weight of _____ lbs/ft³, shall be used to convert weight to volume on this project.

\[
\text{Cubic Yards} = \text{Weight in Pounds} \times \frac{\text{_____}}{\text{_____}}
\]

The estimated quantity includes _______ cubic yards of material in the area between the rock slope and the edge of pavement to be removed and disposed of.

**Figure 15-5 Special Note**

Scaling Conversion Factors Provided by Engineering Geologists
15.3.3 Rock Reinforcing Bolts and Rock Reinforcing Dowels

A rock bolt is a long anchor installed to stabilize rock excavations in tunneling or rock cut operations. It transfers load from the unstable exterior, to the confined (and much stronger) interior of the rock mass. Rock bolts work as tensioned anchors by reducing the driving forces on the blocks within the rock mass and possibly increasing overall stability of the slope. Rock dowels are untensioned anchors that are installed to keep a small block of rock from moving. The Engineering Geologists will identify the installation area, size and strength of steel, pattern or spacing, inclination, minimum length, and design loads of the bolts or dowels.

The design of a rock reinforcement system is dependent upon the physical properties and characteristics of the rock mass including:

- the strength of the intact rock,
- the in situ stress field,
- the spacing, persistence, nature and infill of discontinuities, and
- the orientation of the discontinuities relative to the face of the excavation.

15.3.4 Rock Catchment Fences

Rock catchment fences serve two purposes: to catch falling rocks before they reach the road, and also to serve as a larger storage area as it increases the ditch volume. There are two types of rock catchment fences in use at NYSDOT. The first is a proprietary wire rope net system that is manufactured by specialty fence constructors, the Wire Rope Medium Impact Fence in heights of six, 8, 10, and 12 ft. (See Section 15.4.1 Standard Specification Items). The Temporary Rock Catchment Barrier is a modified version of the Wire Rope Medium Impact Fence, mounted on top of concrete barrier that is used in construction to protect traffic from rock slopes that are scaled after blasting. The other fence system, Chain Link Rock Catchment Fence, is an in-house design using heavy-duty chain link fence and other fence appurtenances commonly available, which can be removed and re-set by NYSDOT Maintenance forces after filling with rock. The smaller and lighter chain link fence system can also be installed up the slope face, as access and right-of-way will allow, to intercept rock falls above the road. For Chain Link Rock Catchment Fence, the Designer must choose either galvanized or vinyl coated wire in order to place the correct Standard Detail in the construction plans.
Figure 15-6 Typical Rock Catchment Fence

Rock catchment fences can be an excellent method for preventing falling rock from reaching the road, but they require a certain amount of space for both their installation and also for deflection during an impact event, as they are designed to be flexible, not rigid.

15.3.5 Wire Mesh Slope Protection and Wire Mesh Drape

Wire Mesh Slope Protection and Wire Mesh Drape are attached to an anchor system at the top of the slope and then are draped over the slope face. The draped system then catches any falling rock and guides it down to the rock catchment area. Wire Mesh Slope Protection is a more robust system than Wire Mesh Drape, for slopes where larger blocks of rock may be expected to fall, and has an anchorage system designed for either rock or soil above the rock slope face, while Wire Mesh Drape uses rock bolts only for the anchorage. Anchor spacing for Wire Mesh Slope Protection and Wire Mesh Drape are based on the weight of the mesh alone.

Draped slope protection systems work most effectively on rock slopes where potential rockfalls consist of individual, relatively small blocks (smaller than 4 ft. in diameter), or many small pieces of rock. If larger blocks are also at risk of falling, the draped system may be installed in conjunction with rock bolts.
15.3.6 Shotcrete

Shotcrete can be used to provide strength to a section of rock slope face that has the risk of small pieces of rock that may fall and undermine larger masses of rock, and can also be used to prevent weathering of rock that is susceptible to deterioration from multiple cycles of wetting and drying. Shale rock that is strong and durable after initial excavation may start to weather and ravel over time, so an application of shotcrete to the rock surface above or below a bridge abutment may be recommended. Shotcrete applications must be installed with drainage weeps so that excess hydrostatic pressure does not build up behind the slope face. Shotcreting may be done in conjunction with rock bolting to increase both global stability and surface durability of the rock slope.

15.4 SPECIFICATIONS

The NYSDOT Standard Sheets provide standard details for the following items typically used in rockfall mitigation:
15.4.1 Standard Specification Items

Item 212.0106  Wire Rope Rock Catchment Fence (Medium Impact – 6 ft.)
Item 212.0108  Wire Rope Rock Catchment Fence (Medium Impact – 8 ft.)
Item 212.0110  Wire Rope Rock Catchment Fence (Medium Impact – 10 ft.)
Item 212.0112  Wire Rope Rock Catchment Fence (Medium Impact – 12 ft.)
Item 212.0201  Chain Link Rock Catchment Fence
Item 212.0202  Vinyl Coated Chain Link Rock Catchment Fence
Item 212.03   Wire Mesh Slope Protection
Item 212.04   Wire Mesh Drape
Item 212.0501 Temporary Rock Catchment Barrier (10 ft.)

15.4.2 Special Specification Items

Item 203.17130017 Resin Rock Bolts – One Inch Nominal Diameter (Grade 150)
Item 203.17140017 Resin Rock Bolts – One and One Quarter Inch Nominal Diameter (Grade 150)
Item 203.33030017 Scaling of Rock Slopes and Removal of Spoil with Blasting – Contractor Supplied Scales.
Item 203.33120017 Scaling of Rock Slopes and Removal of Spoil without Blasting – Contractor Supplied Scales.
Item 583.20010017 Stabilize Rock Slope with Shotcrete (Square Feet)
Item 583.20020017 Stabilize Rock Slope with Shotcrete (Cubic Feet)

15.5 ROCK SLOPE DATABASE AND ROCKFALL DATABASE

The Engineering Geology section of the NYSDOT Geotechnical Engineering Bureau maintains a rock slope database for over four thousand rock slopes adjacent to State highways. The Geotechnical Engineering Bureau’s *Rock Slope Rating Procedure (GEM-15)* outlines the creation of factors for computing relative risk of a rockfall-related accident occurring at any site listed in the Statewide rock slope inventory. This rating procedure has been developed to establish appropriate relationships among the following three separate factors in assessing comparative risks of accidents being caused by rockfalls:

1. Geologic properties of the rock slope. The geologic factor (GF) represents the risk of rock(s) falling, based on the slope’s specific geologic and physical characteristics;
2. Ditch configurations and slope offset from the pavement edge (or shoulder edge where one exists). The section factor (SF) represents the relative risk of fallen rocks reaching the highway's travel lanes. It is related to ditch and shoulder geometry and to rock slope offset; and
3. Traffic volume and stopping sight distance on the highway approaching the site. The human exposure factor (HEF) represents the relative risk of a traffic accident occurring, given that a rockfall occurs and rock comes to rest on the roadway.
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The product of these factors is defined as "Total Relative Risk". The risk assessment model computes relative (not absolute) risk of rockfall accidents occurring along various rock slopes adjoining state highways. That is, the values created by this model do not actually establish how much risk is posed at a particular site, but indicate only whether risk at a given rock slope is more or less than that posed by other rock slopes.

For projects that include rock cuts, the Departmental Geotechnical Engineer should contact the Engineering Geologists to discuss the condition of the rock slope, the history of past rockfall events, and determine the Rock Slope Rating Procedure Relative Risk and priority for that highway and for the Region.

15.5.1 Rockfall Database

Engineering Geologists at NYSDOT developed a Rockfall Database in conjunction with the Rock Slope Inventory Database. When a rockfall occurs along a State highway, the rockfall is reported to the Engineering Geologists by Transportation Maintenance personnel. After the rockfall report is received, an Engineering Geologist goes to the rockfall site to document the source area of the rockfall, assess the stability of the rest of the rock slope, photograph and locate the rockfall with GPS, and make recommendations to Regional Maintenance if further action is required to stabilize the slope. The history of rock falls along a section of road may require that rockfall mitigation techniques be used to stabilize the slope or slopes, either by Maintenance forces or by a contract for the rock work.

15.6 REFERENCES


