ROCK SLOPE STABILITY: DESIGN, CONSTRUCTION AND REMEDIAL TREATMENT

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INTRODUCTION

The design and construction of rock slopes with emphasis on stability began with the ability to drill and blast on an alignment whereby the final slope product was sound and durable and free of potential rock fall hazards. The first attempt at constructing a planar surface in rock was not for a highway but for construction of the sides of an intake channel for the "Niagara Power Project" in Niagara Falls, New York. The extra effort to develop a vertical planar surface for the intake channel was not to prevent potential rock falls but to establish a surface whereby the concrete channel wall liners could be built with a minimum overrun in concrete quantities. (When one considers that the majority of the listed 38,846,000 cubic yards of excavation was in rock, and that several million square feet of rock face had to be prepared within a tolerance of six (6) inches, it is easy to see that quite a problem was presented to the various contractors to keep from overbreaking beyond the payline, or "B" line, as it was called, with conventional methods of drilling and blasting). The method for constructing the planar face was named "presplitting".

The results of "presplitting" in constructing the vertical planar rock wall were so good that it soon was considered to be worthy of utilization in establishing minimum maintenance, hazard free rock faces for highways, tunnels, building foundation excavations and other locations where rock stability is a major concern. New York State Department of Transportation incorporated "presplitting" in its EXCAVATION SPECIFICATIONS on August 27, 1970 by inclusion in Addenda 49 to the January 2, 1962 PUBLIC WORKS SPECIFICATIONS. Once the "presplitting" tool was in place for constructing a stable rock slope, the Engineering Geologist could then put his knowledge to work to establish a suitable rock slope design. This method of construction leading to proper design is another example of empirical knowledge's ability to make theory, fact.

ROCK SLOPE DESIGN

Engineering geologists must consider two major items in designing slopes for a proposed rock cut, stability and cost. The engineering geologist must also use every method available to obtain the structural discontinuities present in the bedrock before designing the slope. The most reliable information may be obtained from outcroppings present in the area of the design. Often however, the outcrops are one dimensional and without a cross section view of substantial extent, the structural information obtained may be misleading. Oriented rock cores from strategically located drill holes, video taped information from television borehole cameras, refraction seismic data, remote sensing equipment and electrical resistivity are methods which can be employed in confirming surficial structural detail and/or portraying attitudinal changes which must be known by the designer to establish a structurally sound slope design.

Plotting the joint, bedding, shear zones and cleavage planes on a stereo-net will enable the designer to detail a stable slope for any particular rock cut.

The cost of excavation for the alignment of any highway project in rock is usually more expensive than for any other type of material. The present bid prices received in New York State for rock excavation average \$30/cubic yard whereas soil excavation averages \$6.50/cubic yard. Many other items such as right-of-way costs, environmentally protected area (swamp) replacement and special cases (i.e. slum evasion) take precedence in corridor selection over avoidance of rock excavation. Excavation and embankment balance is not as important a factor in highway corridor selections as it once was. The material balance is however a prime consideration in Westchester County since no soil borrow areas are available.

Rock slope designs in New York State range from vertical (rarely) to a one vertical on one and one quarter horizontal (38°-40') which approaches the stable angle of repose of talus (37°-30'). Common slope angles of three vertical on one horizontal (71°-34'), two vertical on one horizontal (60°-15'), three vertical on two horizontal (56°-19') and one vertical on one horizontal (45°) are utilized to enable construction of accurate templates for the control of presplit drill alignment.

Vertical drill holes are rarely used and never in slopes greater than 15 feet in height since they create an illusion of toppling causing drivers to inadvertently drift away from the rock face and into oncoming traffic. Vertical design in shallow limestone cuts is sometimes used to avoid intersection of the standard vertical jointing by presplit drill holes. Explosively generated gasses intersecting the vertical joints provides pressures which cause sliding of limestone blocks along its bedding planes toward the open rock cut face. The resulting product is an unstable slope rock.

The one vertical on one horizontal slope is used for stable rock cuts in competent shales, siltstones or bedrock containing structures which dip toward the free face on a 45° inclination.

Rock slopes are constructed on the flatter talus slope if the material to be excavated is deeply weathered and/or fractured. Poor quality horizontally bedded shales will maintain stability on the talus slope. Both the deeply weathered rock and the poor quality shales will achieve total stability on the talus slope angle provided seeding is included following completion of construction. Pre-splitting is not required for the one vertical on one and one quarter horizontal slope since 1) it is extremely difficult to drill on such a flat an angle; 2) the rock can usually be broken by mechanical ripping or light explosive loads in vertical drill holes before final grading with a dozer on the slight incline and 3) seeding covers any discontinuities while greatly increasing the stability and enhancing the esthetics.

The intermediate slope inclinations (3V on 1H, 2V on 1H, 3V on 2H) are used based upon their stability relationship with the inherent structures present in the bedrock to be excavated.

ROCK SLOPE CONSTRUCTION

Two major types of rock slope construction are performed on highway projects, new locations and trim cuts. Trim cutting is for stabilizing previously constructed slopes.

The slopes for rock cuts on new locations are more difficult to design since it involves programming a field evaluation of the site; establishment of a drilling program to delineate the pertinent structures present in the bedrock; plotting the structural features on a stereo-net and finally, establishing the final slope inclination. The design of trim cuts usually is quite straight forward since virtually all of the structural features are available for direct measurement. Trim cuts are made to remove unstable blocks of fractured rock from the slope. This unstable condition was created during the original rock cut blasting construction by excessive explosive gasses generated by standard fragmentation blasting methods employed prior to the advent of "presplitting".

The second most important consideration to be included in trim slope design (slope inclination is first) is to insure that the slab of rock to be removed from the face of the existing slope be a minimum of five (5') feet in width. The control point for the slope face slab offset location is a point a minimum of five feet in back of a point on the slope which is the furthest distance from the centerline of the roadway along the rock slope cut. This point becomes the continuous parallel slope offset throughout the length of the rock cut.

The five foot thickness is required to assure that the presplitting charges break between the three foot spacing of the parallel presplit drill holes rather than towards a closer free face on the slope. This will provide a uniform planar final slope. It also greatly reduces the potential for fly rock.

Construction begins once the contractor is selected. Usually excavation is one of the first stages of the contract work to be performed following the removal of vegetation and topsoil. Rock excavation operations are not seasonal since the work is not limited by temperature restrictions.

Prior to the commencement of drilling operations on any contract, a preblasting meeting is essential. The purpose of the meeting is to:

1 - Learn the date of drilling equipment mobilization.

2 - Establish the procedure for controlling the drill steel alignment in drilling the presplit holes on the design slope inclination. Drill alignment is the most important consideration since the stability of the slope is totally dependent on achievement of the proper slope inclination.

3 - Determine the type and weight per linear foot of the presplitting explosive.

4 - Locate the types of utilities and structures nearest to the blast site.

5 - Specify the maximum pounds of explosives to be detonated per 25 millisecond delay period to insure that blasting induced ground vibrations do not damage any of the utilities and/or structures in the vicinity of the blast site. (Explosive loading limits guide-line follows NYSDOT Standard Specifications for Rock Excavation.)

6 - Determine if a potential for fly rock is is present and if blasting mats are required to protect personnel and property in the blast area.

7 - Insure that the blaster is in compliance with all Local, State and Federal permits, codes, laws and licenses required.

8 - Review the project specifications to enable the blaster and contractor be aware of what they are required to do to construct minimum maintenance, hazard free rock slopes. (Current NYSDOT Standard Specifications follow preblasting meeting subject description.)

9 - Agree upon the location and limits of the rock slope test section area.

10 - Establish the location and types of blasting warning signs, the preblast warning signals and the placement of flag personnel for traffic control.

NYS DOT - STANDARD SPECIFICATIONS of January 2, 1981

as amended by ADDENDUM NO. 1 of December 9, 1982

Section 200

EARTHWORK

§203-3.05 Rock Excavation

Attention is directed to § 107-05, SAFETY AND HEALTH REQUIREMENTS, concerning rock drilling and blasting work.

Presplitting is required where the design rock slope is one vertical on one horizontal or steeper and the vertical height of the exposed rock slope exceeds five feet. Ripping will not be allowed within ten feet of a slope that requires presplitting. Test sections will be required at the outset of presplit drilling and blasting operations for the evaluation of the presplit rock slopes by a Departmental Engineering Geologist. The Contractor will be required to completely expose the presplit rock face in the test section for evaluation prior to any further presplit drilling.

All rock slopes shall be thoroughly scaled to the satisfaction of the Engineer. For rock excavations involving multiple lifts, scaling of upper lifts shall be completed prior to drilling and fragmenting of lower lifts. Scaled rock slopes shall be stable and free from possible hazards of falling rocks or rock slides that endanger public safety. If, after proper scaling, such conditions still exist, a determination of the cause will be made by a Departmental Engineering Geologist and if it is determined that the conditions are the result of poor workmanship or improper methods employed by the Contractor, the Contractor shall provide approved remedial treatment, at no expense to the State. Such treatment may include, but is not necessarily limited to, laying back the slope, rock bolting, or shotcreting. In no case shall the subgrade be trimmed prior to the completion of the scaling operation at any location.

A. Presplitting. Prior to drilling presplitting holes, the overburden shall be completely removed to expose the rock surface along the presplitting line. The methods of collaring the holes to achieve proper inclination and alignment shall be approved by the Engineer.

The presplitting holes shall be a maximum four inches in diameter, spaced not more than three feet center to center along the slope, and drilled at the designed slope inclination for a maximum slope distance of 60 feet. When excavation operations are conducted in multiple lifts, the presplitting holes for successive lifts may be offset a distance of not more than three feet for a design slope of one vertical on one horizontal and not more than one foot for slopes of steeper design; however, a presplitting hole shall not be started inside the payment line. If presplitting is conducted in lifts, each lift shall be approximately of equal depth. All presplitting holes shall be checked and cleared of obstructions immediately prior to loading any holes in a round. All presplitting holes shall be loaded with a continuous column charge manufactured especially for presplitting which contains not more than 0.35 pounds of explosive per foot. The top of the charge shall be located not more than three feet below the top of rock. A bottom charge of not more than three pounds of packaged explosive may be used; however, no portion of any bottom charge shall be placed against a proposed finished slope. Each presplitting hole shall be filled with No. 1A Crushed Stone Stemming meeting the gradation requirements of § 703-02, Coarse Aggregates. The presplitting charges shall be fired with detonating cord extending the full depth of each hole and attached to a trunk line at the surface. Detonation of the trunk line shall be with blasting cap(s) and shall precede the detonation of fragmentation charges within the section by a minimum of 25 milliseconds. Pre-splitting shall extend for a minimum distance equal to the burden plus three feet beyond the limits of fragmentation blasting within the section.

B. Fragmentation Blasting. Fragmentation holes, or portions thereof; shall not be drilled closer than four feet to the proposed finished slope. Where presplitting is required, fragmentation holes adjacent to the pre-splitting holes shall be drilled parallel to the presplitting holes for the full depth of the production lift at a spacing not exceeding the spacing of the production pattern. Only packaged explosives shall be used ten feet or less from a design slope which requires presplitting regardless of the construction sequence.

Fragmentation charges shall be detonated by properly sequenced millisecond delay blasting caps.

EXPLOSIVE LOADING LIMITS

In the absence of more stringent requirements, the maximum quantity of explosives allowed per blast shall be based on a maximum particle velocity of 1.92 inches per second at the nearest structure to be protected. In the absence of seismic monitoring equipment, the following explosive loading limits shall apply:

<u>Distance Equal to or Less than Two Hundred and Twelve (212) Feet from the Nearest Structure</u>

1. When the distance from the proposed blasting area to the nearest structure to be protected is six (6) linear feet or less, no blasting will be allowed.

2. When the distance between the blasting area and the nearest structure to be protected is greater than six (6) and equal to or less than fifteen (15) linear feet, a maximum of one quarter pound of explosive per delay period* blasting cap shall be allowed.

3. When the distance between the blast area and the nearest structure to be protected is greater than fifteen (15) and equal to or less than two hundred and twelve (212) linear feet, a Scaled Distance of thirty (30) shall be utilized to determine the maximum pounds of explosive allowed per delay period* blasting cap. The Scaled Distance Formula is as described below:

$$SD = \frac{D}{\sqrt{E_{Max}}}$$

OR

$$E_{MAX} = \left(\frac{D}{SD}\right)^2$$

Where:
SD = Scaled Distance
D = Distance from blast area to nearest structure to be protected in linear feet

E_{MAX}= Maximum pounds of explosive per delay period* blasting cap

<u>Distance Greater than Two Hundred and Twelve (212) Feet from the Nearest Structure</u>

4. When the blaster elects to utilize more than fifty (50) pounds of explosive per delay period* blasting cap, a seismograph shall be employed to monitor the blasting vibrations generated. The initial loading shall be computed using a Scaled Distance of thirty (30). The resulting particle velocity measured by the seismograph shall be evaluated by a Department Engineering Geologist. His evaluation shall be the basis for adjusting the Scaled Distance.

No separate payment will be made for this work. The cost shall be included in the appropriate excavation item. The above requirements shall in no way relieve the Contractor of liability for any damage incurred as a result of his blasting operations.

*a delay period shall be a minimum of twenty five (25) milliseconds.

PRESPLIT DRILLING, BLASTING AND TEST SECTION REVIEW

A. Presplit Drilling: The Engineering Geologist must be present at the rock slope test section area on the date of mobilization. It is very important that the Contractor's driller and the project inspector learn from the start exactly what is expected of them to insure that drilling alignment control agreed upon at the preblasting meeting is performed.

The following drilling check list is provided to assist the driller and inspector in achieving the final slope as designed. Establish that:

1 - Overburden is stripped from bedrock along the top of the presplit line. Insure that the bedrock surface is not overexcavated as in the case of weak shales.

2 - The drill steel is straight and in satisfactory condition.

3 - The plumb line for orienting the drill steel alignment is correctly located on a line parallel to the presplit line. (Preblast meeting agreement.)

4 - The slope inclination template is the proper dimension and that a minimum two foot long carpenters level is attached to the template. (Preblast meeting agreement.)

5 - The drillers assistant has achieved the proper drill steel alignment as the drill bit is collared by the bedrock surface. (The alignment can only be assured at this time since once the drill progresses into the rock it is literally on its own.)

6 - The drill hole is of the proper depth (including sub-drilling) for each hole.

7 - The presplit drill holes are located on three foot centers.

8 - The driller is using a carbide insert cross bit rather than button bits and a solid drill steel rather than spiral drill steel. The button bits and spiral drill steel are not specifically banned from use but are strongly suspect to cause wander in deep (30 feet plus) drill holes. Drill steel wander is checked for on exposure of the test section face.

9 - The closest row of production (fragmentation) holes to the presplit line is drilled no closer than four feet to and on the same angle as the presplit slope holes.

B. Blasting: The following check list is presented to enable the blasting inspector to determine that the initial test section blast and all future presplit blasting operations are conducted in a manner whereby the best possible rock slope alignment may be achieved.

The inspector shall check:

1 - The depth of each presplit hole to insure that no blockages are present prior to explosive loading. If explosives are loaded following hole check and the adjacent hole is blocked, you would be unable to bring in a drill to clear the hole.

2 - The presplit explosive weight to insure that it is not heavier than the specified maximum weight of 0.35 pounds per linear foot. It is recommended that the inspector count the number sticks of explosive, multiply by the standard length of each cartridge to obtain the total cartridge length of the box and divide the box weight by the cartridge length. This is a good way to check the manufacturers quality control and to prevent manufacturers errors from the disrupting the proper construction of the presplit slope. The explosives is also very important for determining the maximum pounds of explosives per delay period blasting cap when blasting vibration control is a consideration.

3 - To insure that the presplit line is loaded a minimum distance of nine feet in advance of the closest loaded production hole in the section. This insures that the greater quantity or gas generated by the larger production explosives does not follow an open joint, fracture or bedding plane to a point behind the intended presplit slope and thereby disrupt the slope continuity.

4 - To see that the earliest sequenced delay detonator is affixed to the presplit trunk line detonating card. This will insure that the presplit slope is blasted prior to any production hole by a minimum of 25 milliseconds.

5 - For use of free flowing explosives (ANFO, Prills or Water gels) in the production blasting operations and insist that none be used in any production holes located within 20 feet of the presplit slope.

6 - That the stemming material to be used is a #1A crushed stone rather than crushed gravel. Crushed gravel has rounded edges and shotguns out of the hole rather than locking together to keep the presplit explosive gasses in the hole to split the bedrock.

C. Test Section: The establishment of the test section is of enormous value to the Engineering Geologist.

1 - The test section exposes all discontinuities present in the bedrock. Since even the most advanced design exploration methods cannot reveal every feature

present, the test section will enable the Engineering Geologist to determine if the slope will be stable as designed. If it is determined upon evaluation of test section that the slope is unstable, the Engineering Geologist can change the slope design to one which will be stable. The contractor will not be detained for more than a day and can than proceed with the rock slope construction on the new slope inclination.

2 - The test section examination will also reveal if the presplitting explosive is too heavy or too light as evidenced by the presplit hole drill butt trace which remains.

3 - The drill butt trace also provides direct evidence if drill attitude at the time of initial drill set up and any drill wander as it occurs from the top of the slope to the bottom.

Direct measure at the top indicates if the initial alignment was correct. Drill butt traces which curve in parallel paths can be attributed to spiral drill steel. Diverging or crossing drill butt traces can be blamed on use of button bits or initial improper drill alignment. Diving drill steel which causes an over steepened unstable rock slope can be related to alternating horizontal hard-soft beds (i.e. Sandstone - Shale); excessive down pressure on the drills by the drill head causes drill steel to knuckle downward in a hard bedrock medium and finally gravity can be found to be the culprit in soft shales and siltstones. A diving drill steel can be corrected by the driller commencing the drill at a flatter angle at the surface to achieve the proper slope at the toe.

Rarely does a drill kick out to cause a flatter slope. If this does occur, it is usually due to improper driller setup. Occasionally a drill bit will intersect an open void whereby the drill strikes the bottom surface of the void on an acute angle which dips toward the roadway.

ROCK SLOPE STABILIZATION

We have all seen signs along highways throughout the country which state "Caution - Falling Rock Zone". Falling rock is basically a seasonal phenomena. Rock which is cyclically moved toward a free face by frost wedging, ice buildup, heavy rain fall and snow melt occurs usually in late autumn and early spring when its center of gravity moves over the edge of its adjacent precipice. This is only one small incident which undoubtedly will miss any auto on the roadway and if it does hit a vehicle, the operator treats it as an "Act of God" and complains to no one but his insurance company. The fact that there is a minimum of complaints registered with highway agencies is why little is done to correct them.

A recent (January, 1988) rock slide on the New York State Thruway at Elmsford resulted in the death of one woman and injury to another. This event and the publicity generated by the news media prompted political pressure to be heaped on the New York State Thruway Authority and the New York State Department of Transportation to delineate unstable rock slope problem areas and stabilize them.

The New York State Thruway Authority budgeted $30 million for rock slope stabilization operations to be conducted over the next several years. A great amount of this type of work has been completed in the 20 month period since the accident.

There are six major types of rock slope failures and each has occurred in New York State to various degrees. The remainder of this text will describe the failure types, the occurrence location(s) and the recommended remedial treatment which will correct the situation.

1 - Plane Failure:

Plane failure occurs when a geological discontinuity, such as a bedding or foliation plane strikes parallel to the slope face and dips into the excavation at an angle greater than the angle of friction.

A plane failure on a bedding plane is found along Route 52 west of Ellenville on Shawangunk Mountain in the Shawangunk quartz pebble conglomerates and metamorphic quartzite grits. (Stop 7) A plane failure on a foliation plane in gneiss along Route 4, between Fort Ann and Comstock in Washington County.

The most economical remedial treatment for stabilization of this condition is rock bolting. The most recent innovation in the rock bolting arena is the introduction of a resin rock bolt anchor system. A hole capable of receiving a three quarter inch to one and one half inch diameter grade 150 reinforcing steel bolt threaded on one end is drilled to a depth three feet beyond the failure plane.

Cartridges of a fast set (three to five minute set time) are loaded in the bottom of the hole followed by slower setting cartridge of resin (15 to 20 minute set time). The bolt is inserted and spun with an impact hammer to mix the two component resin cartridges for a full minute mix time. The pull tester is then attached to the rock bolt and after the fast set resin is hardened, the bolt is pretensioned to the specified strain pressure and maintained until completion of the slow set time of hardening. The pull tester is then released and removed and appropriate plate, beveled washer and nut are attached and snug tightened. The strain resistance of the resin has not been determined to date. They have been on the market for approximately ten years and no failures to date have been reported. It is however the best anchorage in rock devised to date. An epoxy resin was tested previously but was found to be unable to maintain anchorage in wet holes.

The purpose of the rock bolt is to increase the coefficient of friction along the shear plane thus preventing initial movement of the block to be retained. Should the block move, the bolts could not hold it and would either pull out or snap like tooth-picks.

2 - Wedge Failure:

When two discontinuities strike obliquely across the slope face and their line of intersection daylights in the slope face, the wedge of rock resting on these discontinuities will slide down the line of intersection, provided that the line of inter-section of this line is significantly greater than the angle of friction.

A major wedge failure on Interstate Route 84 near the top of Hosner Mountain in southeastern Dutchess County on April 15, 1982 closed the three eastbound lanes of the highway. An estimated 2,500 cubic yards of rock was subsequently removed. The cleanup was completed by the State and two contractors in a three week time period. It was determined that the slide was caused by heavy rain fall during the week prior to the slide. The rain decreased the coefficient of friction on the slide plane and created excessively high hydrostatic pressures which triggered the failure. (Stop 6)

3 - Circular Failure:

When the material is very weak, as in a soil slope, or where the rock mass is very heavily jointed or broken as in a rock fill, the failure will not be defined by a single discontinuity surface but will tend to follow a circular failure path.

Circular failures are found in the clays of Troy and Central Albany County; in the talus slopes in the high peaks region of the Adirondack Mountains and in the diorite talus along the west side of Route 9W in Haverstraw, Rockland County.

Circular soil failures are often balanced with a counter weight berm and soil anchors and weep drains to move the water away from the failure plane. Talus failures are counteracted with retaining walls.

Circular failure in a deeply weathered gneiss will be seen at West Point at the intersection of Route 9W and 218. (Stop 2) At the West Point failure area, a gabion catch wall constructed along the front edge of a bench is used to catch rather than correct the problem.

4 - Critical Slope Height versus Slope Angle Relationship:

A high steep slope is certainly much more unstable than a low flat slope. The factor of hydrostatic pressure and frost wedging created when rain fall lands on the high steep slopes causes major rock falls and slides to be initiated. The deep tension joints created by stress release following Pleistocene glacial retreat left major repositories for water buildup and resulting hydrostatic and frost wedging to move enormous blocks of rock from the top of the high steep rock faces.

A major example of this condition may be found along Route 218 - Old Storm King Highway in eastern Orange County between West Point and Cornwall along the west bank of the Hudson River. Trim blasting at the top of slope and rock bolts have been used in an attempt to reduce the major falls but small spalls of rock from the face nearly covered the highway when it was closed for the limited rock slope remedial treatment. Rock falls of such enormous magnitude located as far as 1000 linear feet west of Route 218 fall from the tops of cliffs over five hundred feet in height into a huge talus pile. Desk sized talus splash material has reached Route 218. No treatment or catch scheme is available to deal with this situation.

5 - Toppling Failure:

A toppling failure occurs when a block of rock which is higher than it is wide is positioned on a slope which is intersected by one or more joint planes which dip steeply into the slope of the rock face. The coefficient of friction is approaching zero along its base. Water penetrating the steeply dipping joint plane will easily dislodge the block and cause it to topple. Normally the joint plane is located in a relatively parallel plane with a whole family of joints. Once the initial block topples, a domino effect is established.

A toppling failure condition is to be found along Route 97 at Sparrow Bush in southwestern Orange County.

Rock bolting of substantial length is recommended to increase the width of the base of the block to exceed the toppling moment. Bolt lengths would increase proportionately with the block height.

6 - Ravelling Slopes:

Small spalls of rock which are found at the base of all rock slopes are caused by two prime factors, cyclical wetting and drying and/or freezing and thawing and deterioration of the cement matrix due to weathering processes.

This is not a major problem for highway slopes as it rarely causes more damage than a small dent or scratches in vehicles. Vehicles grind them to powder and snow plows sweep them off the highway into the ditch. Larger sized spalls of the size of baseballs to basketballs may be restrained and prevented from reaching the highway by a wire mesh screen draped over the slope. The screen is strung from cables attached to rock bolts. This method of correction has been applied by the New York State Thruway Authority at several sites located between Newburgh and Albany. The first application of the wire mesh draped over the slope was used on Route 52 east of Ellenville in Ulster County in 1975. (Stop 8)

Several types of rock catch methods have been utilized to contain or deflect problem rock falls without correcting it. The most common methods are a collection ditch at the toe of slope, rock catch fences and double corrugated beam guide railing.

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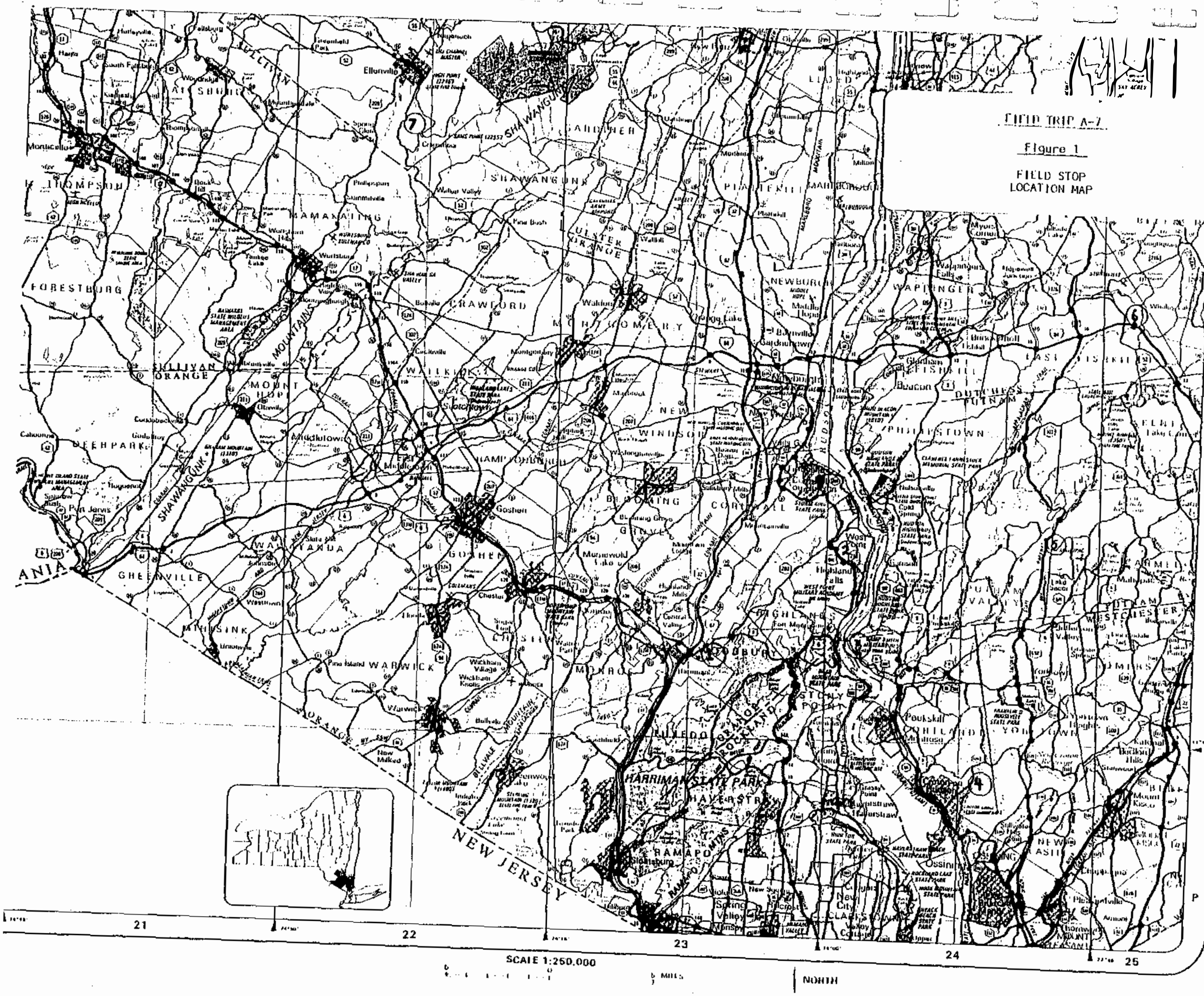
ROAD LOG FOR ROCK-SLOPE STABILITY: DESIGN, CONSTRUCTION, AND REMEDIAL TREATMENT TRIP A-7

	Cumulative Mileage	Miles From Last Point
Left onto Bennett Street from OCCC parking lot.	0.0	
Right at stop sign onto Route 17M east.	0.2	0.2
Right onto ramp for Route I-84 east.	1.9	1.7
Take Exit 4E to Route 17 east.	5.5	3.6
Take Exit 131 to Routes 6, 17 and 32.	22.8	17.5
Turn right at light at end of ramp.	23.1	0.3
Turn left at first light onto Route 6 east.	23.3	0.2
Enter first parking area on left.	25.2	1.9



FIELD TRIP A-7

Figure 1

FIELD STOP LOCATION MAP

STOP 1: Slope has two (2) lifts. A few bolts are in the top lift across from the west end of the parking area. There are more bolts near the location marker.	Location Marker: 6 8301 2362	
Leave parking area and continue east on Route 6.	25.3	0.1
Bear left on Route 292 north.	26.4	1.1
Bear right onto Route 9W south.	33.3	6.9
Park on shoulder just past exit for for Route 218.	34.5	1.2
Walk back to the exit ramp.		
STOP 2: Slope has two (2) lifts. A gabion wall is installed on the bench. There are numerous bolts in the upper face. A large dike cuts through the center of the face.	Location Marker: 9W 8302 1047	
Continue south on Route 9W to traffic circle.	38.9	4.4
Take third exit off circle to Route 6 east (Bear Mt. Bridge).	39.0	0.1
Pay Bridge Toll.	39.1	0.1
Turn right at east end of Bridge to stay on Route 6 east	39.6	0.5
Pull into parking area on right.	40.4	0.8
Walk back toward Bridge.		
STOP 3: There are several areas between the the parking area and the Bridge which have rock catchment fences, rock bolts and/or buttresses.	Location Marker: 6 8703 1009	
Continue east on Route 6 to traffic circle.	43.2	2.8
Take first exit off circle towards Routes 6 east, 9 south & 202 south.		

Turn right at end of bridge onto Route 9 south toward Peekskill.	43.4	0.2
Continue south on Route 9 to exit for Routes 9A & 129 to Croton-on-Hudson.	51.0	7.6
Turn left at bottom of ramp onto Route 9A south.	51.2	0.2
Turn left at second (2nd) light onto Route 129 east.	51.4	0.2
Intersection of Route 129 and Old Post Road.	51.8	0.4
Downtown Croton-on-Hudson on left. (Pit Stop?)		
Continue east on Route 129 and park at entrance to Croton Gorge Park.	53.5	1.7
Walk east on Route 129 to work zone on westbound side of road.		

Location Marker

STOP 4: Rock Slope Stabilization Project. Slope is being trimmed to an inclination of 1 vertical on 1 horizontal.

129 8701 1022

Continue east on Route 129.		
Cross new bridge over New Croton Reservoir.	55.2	1.7
Turn left at sign for Taconic State Parkway (T.S.P.) (Underhill Ave.).	56.8	1.6
Go under T.S.P. and turn left onto ramp for T.S.P. Northbound.	57.7	0.9
Turn right onto Bryant Pond Road.	66.8	9.1
Take first left onto Wood Street.	67.0	0.2
Bear left at Bullethole Road sign.	68.3	1.3
Stop at road work sign just before T.S.P.	68.5	0.2
Walk north on T.S.P. behind jersey barriers to work zone.		

Location Marker

STOP 5: Shoulder is being widened and rock slope is being trimmed to an inclination of 2 vertical on 1 horizontal.

TSP 8402 1045

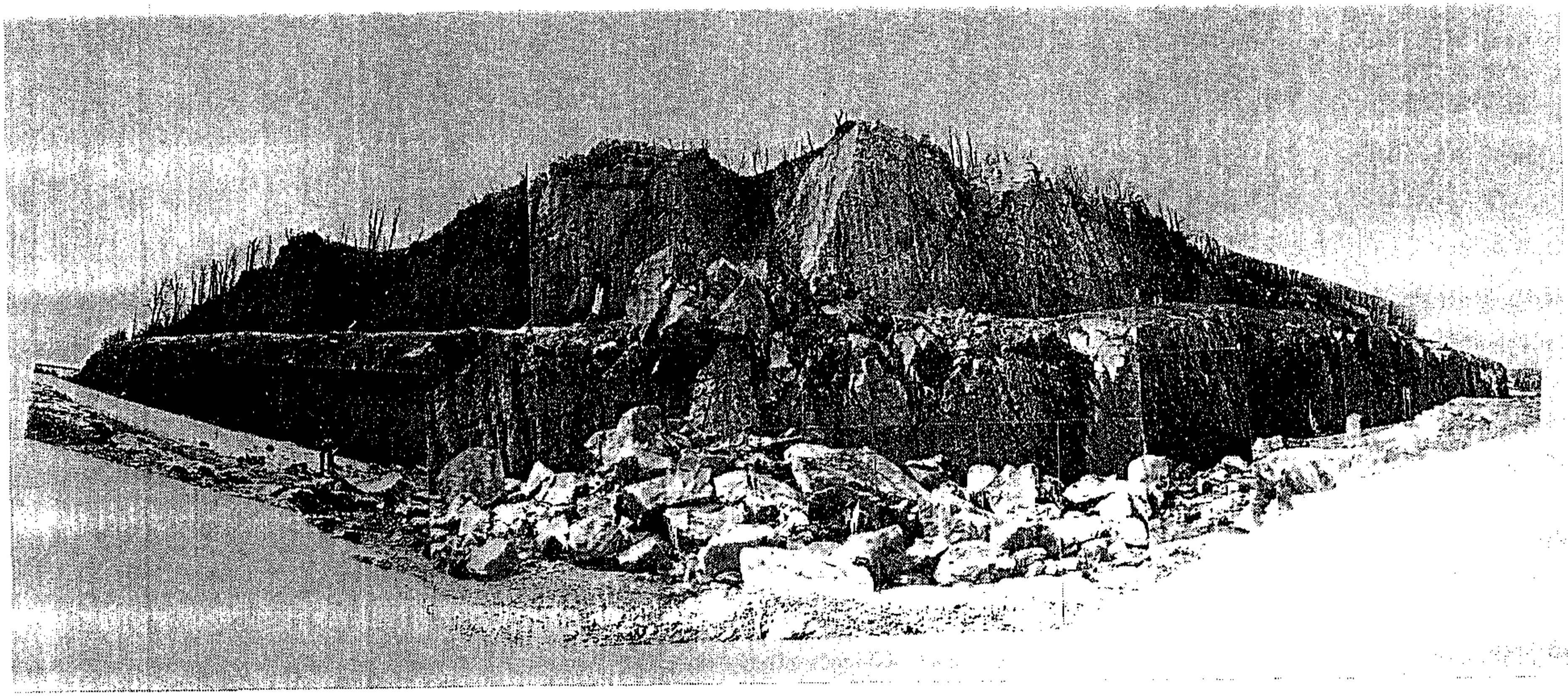
Continue north on T.S.P. Turn right onto ramp for Route I-84 east.	81.1	12.6
Go east on Route I-84 to Exit 17 (Ludingtonville).	87.2	6.1
Turn left at end of exit ramp.	87.5	0.3
Go under I-84 and turn left onto ramp for I-84 west.	87.6	0.1
Go west on I-84 to first rest area.	90.9	3.3
Walk east on I-84 to rock cut.		

	Location Marker
<u>STOP 6</u>: Vertical slopes on both sides of highway and in median. Massive wedge failure scar on south slope. (Fig. 2).	84I 8202 1154

Leave rest area and continue west on I-84.	91.3	0.4
Cross Hudson River and continue west on I-84 to Exit 8 (Route 52).	109.2	17.9
Turn right at end of exit ramp onto Route 52 west.	109.3	0.1
Turn left at light in Walden to stay on 52 west.	118.1	8.8
Park on wide shoulder on east-bound side of 52.		
Walk down hill along Route 52.		

	Location Marker		
<u>STOP 7</u>: Several areas showing thick mylonite zones, rock bolts & wedge failures. Catchment mesh at mile 134.9	52 8602 1127	134.9	16.8

Continue west on Route 52		
Turn left onto Route 209 south in Ellenville.	137.3	2.4
Turn left onto ramp to Route 17 east.	150.8	13.5
Park on shoulder at top of mountain.	152.8	2.0



FIELD TRIP A-7

Figure 2

ROUTE I-84 ROCKSLIDE
Dutchess County, N. Y.
April 15, 1982

STOP 8: Rock slopes on both sides of highway. There is a wide bench on the south side with a guard rail installed at the edge to act as a catchment.

Continue east on Route 17 to Exit 118A (Route 17M - Fair Oaks).		159.5	6.7
Turn left at end of ramp onto Route 17M East.		159.6	0.1
Turn right on Wickham Ave. in Middletown to stay on 17M East (Route 211 West).		163.6	4.0
Turn left on Monhagen Ave. to stay on 17M East (211 West turns right).		164.4	0.8
Turn right on Academy St. to stay on 17M East.		165.2	0.8
Route 17M East bears right onto Dolson Ave.		165.4	0.2
Turn right on Bennett St.		165.6	0.2
Turn right into O.C.C.C. parking lot.	TOTAL	165.8	0.2