REVIEW AND CASE EXAMPLES OF ROCKFALL PROTECTION MEASURES IN THE MOUNTAIN REGION OF CANADIAN NATIONAL RAILWAY

by

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ABSTRACT

This paper describes rockfall protection measures carried out by Canadian National Railways in the mountain terrain between Jasper and Vancouver and between Jasper and Prince Rupert. Track obstructions due to rock fall, mudslides and avalanches have over the years been a serious problem to rail traffic jeopardizing the safety of personnel and causing derailments and delays to train operations. Early methods of track protection included the construction of rock and snow sheds but to a large extent precarious locations on the mainline railway were monitored by track patrolmen. Basic rock slope maintenance and the introduction of slide detector fences in 1949 provided further insurance against potential and undetected rockfall. In 1971 CN Rail commenced a major program to provide added safety and reliability for the movement of trains through hazardous locations by using rock stabilization techniques. Since 1971 almost $2 million per year has been spent on rock stabilization work mostly on the Yale and Ashcroft Subdivisions between Hope and Kamloops.

Rock stabilization measures include scaling, rock bolting and shotcreting of unstable and weathered rock conditions. Much of this work is carried out by contractors within time constraints to permit on-time train movements through the work area. Since the inception of a major rock fall protection program in 1971 the number of derailments has been reduced substantially even though rail traffic densities have significantly increased.

This paper discusses the stabilization program in general and describes work recently done at 2 specific sites.

Keywords: site inspection, slide detector fence, rock bolts, shotcrete.

REVIEW OF ROCKFALL PROTECTION PROGRAM

BACKGROUND

West of Jasper CN Rail operates 1934 km. of main line track serving the ports at Vancouver and Prince Rupert. A significant part of this route is in difficult mountain terrain. The most difficult terrain is encountered along the canyon sections of the Thompson and Fraser Rivers, along the Skeena River and in the Yellowhead Pass area between Jasper and Valemount. Shorter sections of steep mountainous terrain also occur at many other locations. Appendix 1. shows the location of the CN Rail mainline through northern and southern British Columbia.

In the areas prone to frequent rock, mud and avalanche events a few concrete and timber sheds were built during construction of the original railway to protect the track. In 1949 slide detector fences were installed to warn train crews of a slide occurrence within the limits of the fence.

In the 1940's and 50's men referred to commonly as "rock rollers" were employed to ride the lead locomotive and remove rock and other obstruction from the track. This required the trains run at reduced speeds in hazardous locations in order to stop in advance of an obstruction. This time-consuming method of surveillance gave way to patrolmen on velocipedes who patrolled hazardous sections of track on beats of 8 km., over which each patrolman made between 2 and 3 round trips per shift.

During 1961 and 1962 the velocipede patrols were gradually replaced with motorized patrols, radio equipped, and operated by one man, with a beat varying from 32 - 40 km. Since the early 60's track motor car patrols have been in effect along 245 km. of the B.C.S.L., predominantly in the Thompson and Fraser canyons. Patrols increase the safety of train operations but do not increase the reliability of operations. Rockfalls immediately after a patrol has passed can still occur. During these years regular scaling of hazardous slopes was carried out but no attempt at stabilization was made.

INCEPTION OF ROCKFALL PROTECTION PROGRAM

CN Rail became aware of the need for an improved rockfall protection program in the late 1960's in an era of increasing rail traffic. A derailment near Boothroyd in February, 1971 had a large impact on the program. At this location a track motor car patrol had carried out an inspection within an hour of the derailment caused by rockfall. Subsequent to the Boothroyd incident a commitment was made by CN Rail to carry out a rockfall protection program to improve the safety and reliability of the track.

Since 1971 between $1 and $2 million/year has been spent on measures intended to prevent rockfalls.

ROCKFALL PREVENTION MEASURES

Sites selected for rock stabilization work are generally those established several years in advance and have been assigned a priority based on previous rockfall activity or anticipated failure. After a detailed site inspection and assessment of geologic conditions the quantity and type of stabilization technique is estimated. The work is usually carried out on a contractual basis.

Rock scaling with scaling bars is carried out as an initial stabilization measure to remove all surficially loose and weathered material. Payment for scaling work is by the man hour where the unit price includes clean-up of rock debris from ditches and the track below which is also covered with granular material to protect rails and ties from damage by scaled rock.

Where potentially unstable rock cannot be removed with scaling bars the contractor will "trim" the rock using drilling equipment and light explosive charges. The drilling equipment may be hand-held or bencher-type depending on the length of the hole and the location of trim work. The quantity and type of explosives used is generally the contractor's choice subject to approval by the CN Rail engineer on site. The optimum drilling pattern for trim holes is estimated prior to the work in order to determine the approximate quantity of total trimming, however, the estimated burden and spacing of trim holes may be modified during the course of a contract according to varying rock conditions. The unit of payment for trimmming is by the metre of hole drilled and blasted where all equipment, labour and clean-up is included in the unit price.

Subsequent to removal of loose surficial rock further enhancement of rock slopes and cuts may be required because of instability brought on by discontinuities such as unfavourable bedding planes and joint sets. In such cases rock bolting is carried out to prevent toppling and sloughing and to increase resistance to sliding. Rock bolts used on CN Rail stabilization work are generally the untensioned-type and vary in length from 3 - 15 m. The most commonly used bolt is the 15 mm diameter H. S. Dywidag Threadbar or equivalent conforming to ASTM A722-75 with an ultimate strength of 197 KN. The specified hole diameter for 15 mm bolts is 47.5 mm when used in conjunction with a cementitous grout. Where a resin grout is used the specified hole diameter is 35 mm. The bolts are test-tensioned to 136 KN on a random basis.

Although grouted rock bolts are considered to provide permanent support a minor quantity of temporary anchors have been installed in conjunction with a shotcrete membrane application in tunnel stabilization work. The temporary bolt used has been the Swellex type as manufactured by Atlas Copco which has a minimum tensile strength of 100 KN. It is installed in a 38 mm diameter drill hole by inflating the re-shaped bolt with a water pressure of 30 MPA.

The unit of payment for fully-grouted 15 mm bolting is by the metre of bolt installed, grouted and test tensioned if requested. Payment for the Swellex bolt of a specified length is a unit cost.

Most rock stabilization contracts include provision for shotcrete application to protect against further weathering, fill voids, provide support and seal fractured rock. Shotcrete work is also carried out in conjunction with the sealing and re-direction of seepage zones which may result in ice formations.

The most commonly used shotcrete mix for is the dry-mix type with a maximum aggregate size of 9.5 mm, however, where shotcrete application is carried out for support in the walls and crown of tunnels a 3% steel-fibre dry-mix has been specified to obtain greater flexural strength. Since shotcrete quantities used on rock stabilization contracts rarely exceed $50m^3$ it is generally more economical for contractors to use pre-mix bagged product.

The most commonly used shotcrete machines on CN Rail work are the Meyco GM060, Aliva 250 and Reed 20 VA IV and typically, the dry-mix product is applied at rates ranging from 2 - 3 m^3/hour. Test panels of the shotcrete product are taken during the period of application and are subjected to compressive and flextural strength tests. The specified compressive strengths for 7 and 28 day tests are 20 MPA and 27.5 MPA respectively and flexural strengths are specified to be a minimum of 15% of the compressive.

The unit of payment for the supply and application of shotcrete is the cubic metre of product put through the shotcrete machine. Although the contractor is not held responsible for rebound, losses are monitored so that a reasonable rebound factor is not exceeded. Included in the unit price of shotcrete is the provision of relief holes and embedded drainage systems.

The contractor must schedule his work within a specified "work block" which is a duration of time when the contractor can execute work without interruption by the passage of trains. The duration of the work block on the main line is normally 4 hours and all contractual work must be done during this time or scheduled around train movements.

The costs of contractual rock stabilization measures depend largely on the scope of work, site access, work block duration and equipment requirements. Unit prices have generally remained stable to lower over the past 5 years.

ROCKFALL DETECTION, PROTECTION AND CONTROL MEASURES

Various measures, other than rock stabilization, are used to detect and protect against rockfall. These measures include the use of slide detector fences, instrumentation monitored by computer, rock sheds, mesh installation and cut widening.

Slide detector fences are erected parallel to the track covering the lengths of unstable rock cuts which cannot be stabilized or where the scope of work is uneconomical . The fence is made up of a series of wires strung horizontally between wooden poles located 16 m. apart. When rock falling from the slope encounters the fence, the fence wires are severed by the impact resulting in the activation of warning signals. The major problem with this method of detection is that insignificant rockfall of no danger to trains, can cause fence activation and unnecessary delays to trains. The problem has in part been solved by suspending Gabion mesh behind the slide fence to trap and prevent minor rockfall reaching the fence wires. On a test basis mesh protection has greatly reduced the frequency of activation by insignificant rockfall. About 13,400 metres of slide detector fence are in service at present in British Columbia.

Instrumentation is currently being used to monitor one location in the Fraser Canyon east of Hope where 6 bridge extensometers have been installed in precarious rock conditions situated approximately 200 m. above track elevation. The extensometers are read and recorded diurnally by a computer located at track elevation. Thus far the data has indicated that no significant displacement has occurred.

Timber and concrete rock sheds, most of which have been constructed since 1926, in highly active rockfall locations continue to provide excellent protection against derailment by rockfall. Since 1971 only 52 m. of rock shed protection have been constructed, however, reconstruction of a 12 m. long shed on the Ashcroft Subdivision in the White Canyon area is scheduled for 1986. Photograph 1: shows location of rock sheds at Mile 94.4 Ashcroft Subdivision B.C. South Line.

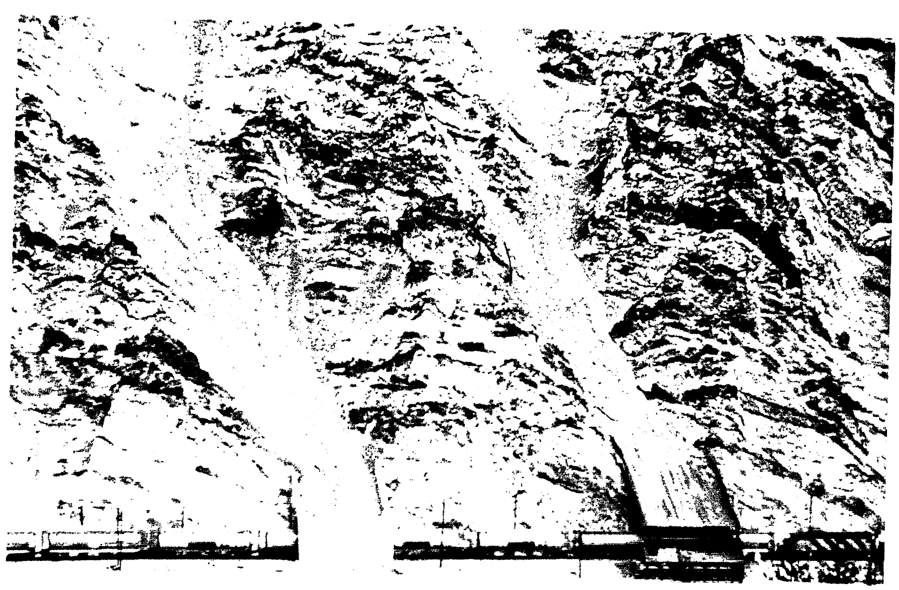

Photo 1. Rock sheds located at Mile 94.4 Ashcroft Subdivision

Measures for the control of rockfall have been carried out recently and include cut widening to accommodate wider and deeper catch ditches and to facilitate track revisions. Wire mesh has been placed on slopes and Gabion catchment walls have been constructed. Rockfall control measures are generally carried out in locations where lesser rockfall activity caused by ravelling rock conditions or movement on scree slopes is a continual problem, not considered of major importance, and is often associated with an on-going maintenance program to avoid accumulations of rock debris.

RESULTS OF ROCK FALL PROTECTION PROGRAM

REDUCTION IN DERAILMENTS

Since the inception of CNR's rock fall protection program in 1971 derailments caused by avalanches, mudslides and rock fall have been reduced significantly. For the route from Jasper to Vancouver records show that between 1956 - 71 a total of 41 derailments caused by track obstructions occurred. Only 25 derailments related to these factors occurred between 1972 - 85. Rail traffic density on this line has increased dramatically from an average of 8.6 million gross ton miles in 1956 to 45.3 million in 1985. To fully represent the effectiveness of rockfall protection measures carried out since 1971 on the 4 subdivisions of the B.C.S.L. a comparison of derailments per 10 million gross ton miles using the average rail traffic densities for the time frames 1956-71 and 1972-85 is shown graphically in Figure 1.

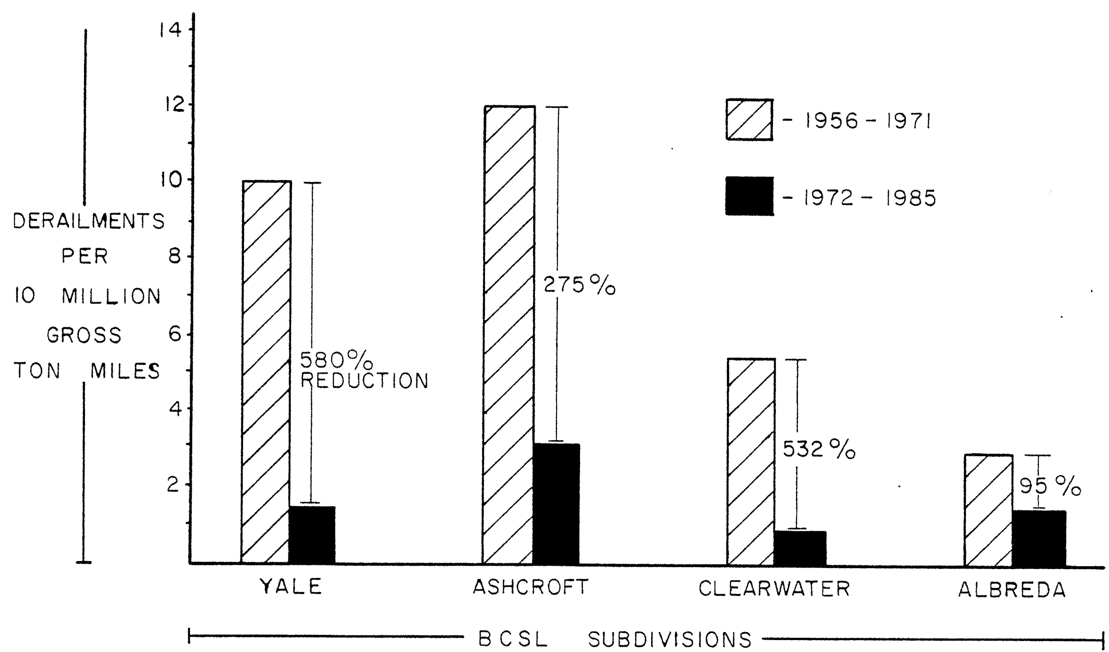

Figure 1. Comparison of derailments relative to average traffic densities - Jasper - Vancouver.

1956-71 vs. 1972-85

Expenditures for rock fall protection programs in the Mountain Region since 1971 have amounted to about $30 million. It is clear that this work has significantly improved safety conditions for the men operating the trains. The reduction in time the track is out of service due to rock falls has also contributed to CN Rail's ability to move increasing volumes of traffic through difficult mountain terrain to the important ocean ports on the west coast.

CASE EXAMPLES

1. ROCK SLOPE STABILIZATION - Km. 13.8 YALE SUBDIVISION

The location, situated approximately 2 km. south of Hell's Gate and 50 km. north of Hope, B.C. was initially identified in 1971. Remedial action, however, was not undertaken since a slide detector fence had been previously installed to provide warning of rockfall activity.

Continual rock fall activity of the blocky granodiorite rock conditions and frequent activation of the slide fence prompted further assessment of the rock conditions to determine the areas responsible for rock fall. A further inspection was made in 1984 during which 2 major areas were identified as the sources of rock fall, one of which was considered extremely hazardous.

Photo No. 1 indicates the areas of concern designated Area No. 1 and Area No. 2 which are situated approximately 120 m. above the track which is partly supported by a retaining wall.

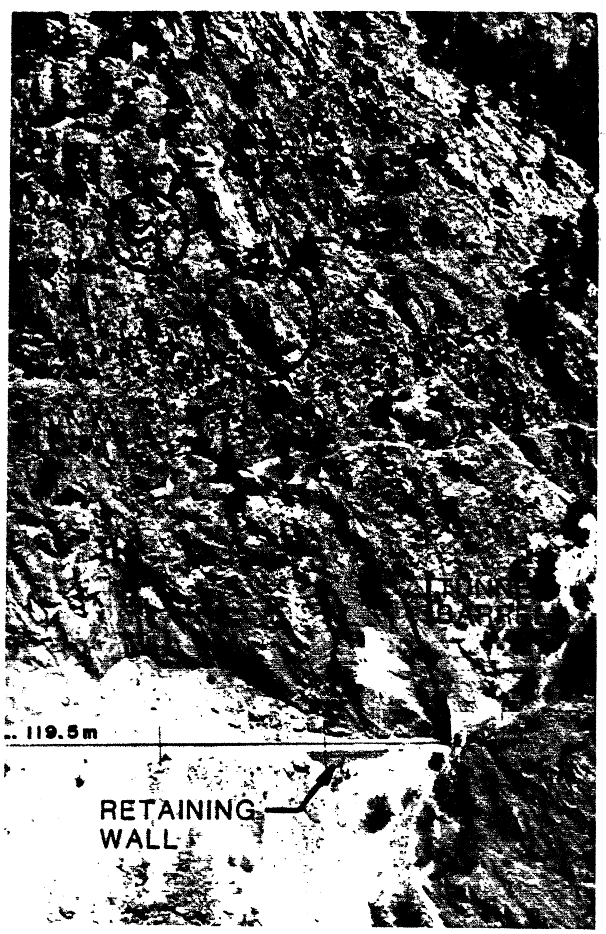

Photo 2. View looking south at Areas No. 1 and No. 2 - Km. 13.8 Yale Sub.

Since stabilization of the rock was not considered viable, a decision was made to remove the unstable rock conditions by controlled drilling and blasting methods.

Prior to commencement of contractual work CN Rail construction personnel met with the Department of Fisheries and Oceans who expressed their concerns over fly-rock from the proposed blasting reaching the Fraser River below. They pointed out that the location is highly critical for fish as the river is very constricted and fly-rock, small or large, going into the river would increase the bed-load and flow velocity and thus impede migration of fish. Thus stringent drilling and blasting techniques were specified to minimize the amount of fly-rock and ensure that the fragmentation size did not exceed 15 cms.

Contract work commenced in May 1985 with the drilling of Area No. 1. Drilling of horizontal 41 mm diameter holes was carried out on 1.3 m x 1.3 m, burden and spacing, for a total of 435 m. of drilling carried out with Atlas Copco bencher feeds BMP32 and BBC 24D rock drills. Drill holes for Area No. 2 were vertical and drilling was carried out with the hand-held Atlas Copco BBC24D rock drills. Drill holes in both areas were loaded with semi-gelatin explosives (Cilgel 70%, 400 x 32 mm) and with Nonel millisecond detonators (delay periods #0 - #5).

The rock volumes to be blasted in Areas No. 1 and No. 2 were calculated from drilling data to be in the order of 650 m^3 AND 200 m^3 respectively and in order to achieve the required fragmentation and to control rock throw an explosives factor of 0.56 kg/m^3 was specified. Although the powder factor was considered optimum, there were concerns that the affects of blasting would loosen rock conditions above Area No. 1. Thus, as a precautionary measure, 25 - 6 m. grouted rock bolts were installed in blocky rock conditions above Area No. 1.

Prior to the scheduled date of the blast authorization was obtained for a track closure of 14 hours duration. The track closure permitted adequate time to "flood" the track below the blast sites with a protective cover of rock and granular material, to blast, scale and subsequently to clean up and dispose of rock debris and cover material.

All hazardous rock was removed from Areas No. 1 and No. 2 and no damage was caused to the railway plant. The amount of fly-rock reaching the river was within the acceptable limits.

2. TUNNEL STABILIZATION - KM.145 BULKLEY SUBDIVISION

Rock conditions in the vicinity of a 42 meter long tunnel about 66 km. north-east of Terrace, B. C. were known to be only marginally stable. The siltstone, argillite and greywacke rocks at the tunnel site are gently folded and appear to be partially metamorphosed. The least stable conditions at the site were associated with the bedding planes along which shear movement had occurred as a result of folding. This has produced varying thicknesses of graphitic gouge along the bedding plane surfaces to form narrow shear zones. The orientation of the bedding planes, approximately 010°/25°W compared to the tunnel alignment orientation of 054°, and the weathering of joints perpendicular to the tunnel were responsible for occasional sloughing along the tunnel walls and minor rockfall from the crown area.

A few months before the site was scheduled for stabilization a failure along the bedding planes at the south approach of the west portal resulted in rock fall which reached the tracks and caused a train derailment. The derailed train then hit the tunnel wall causing collapse of approximately 5 m. of the tunnel and causing further damage to the tunnel crown and south wall beyond the failed area.

The damaged area was immediately scaled and trimmed and the line was opened to traffic protected by a "slow order". However, continued rock falls dictated more substantial methods of stabilization in order to improve safety. A minor stabilization program was carried out under adverse winter conditions to provide the necessary protection measures until a major program could be effected in the following spring. Photograph 3 shows rock conditions at the west portal location.

Initial remedial action consisted of installation of rock bolting and shotcrete work inside the tunnel at the west portal and mesh over the west portal area. To provide support to the tunnel crown and south wall at the west portal 37 - 2.4 m. Swellex bolts were installed. Structural support with 11 m^3 of shotcrete was planned, however, a drop in temperature to minus 35°C dictated the suspension of shotcreting work after 6 m^3 of shotcrete had been applied.

In order to provide protection against further loose rock reaching the track from the west portal location, the entire portal area was covered with 360 m^2 of mesh suspended by steel cable attached to steel pins installed on the slope above the tunnel portal. The mesh was held in place as it covered the portal area by means of rock bolts installed on 5 m centres. These bolts pinned the mesh to the rock face so as to entrap any loosened rock. The 2.4 m friction bolts also provided a limited amount of support to the ravelling siltstone and sandstone bedding. More extensive stabilization measures were scheduled for the following spring in better weather conditions.

Km. 145 Bulkley Subdivision - Tunnel

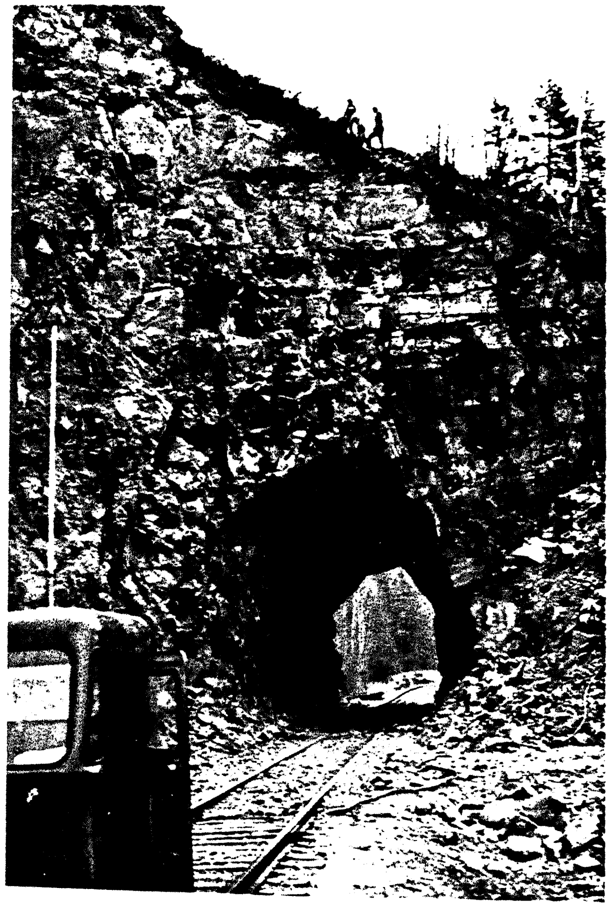

Photo 3. West portal view

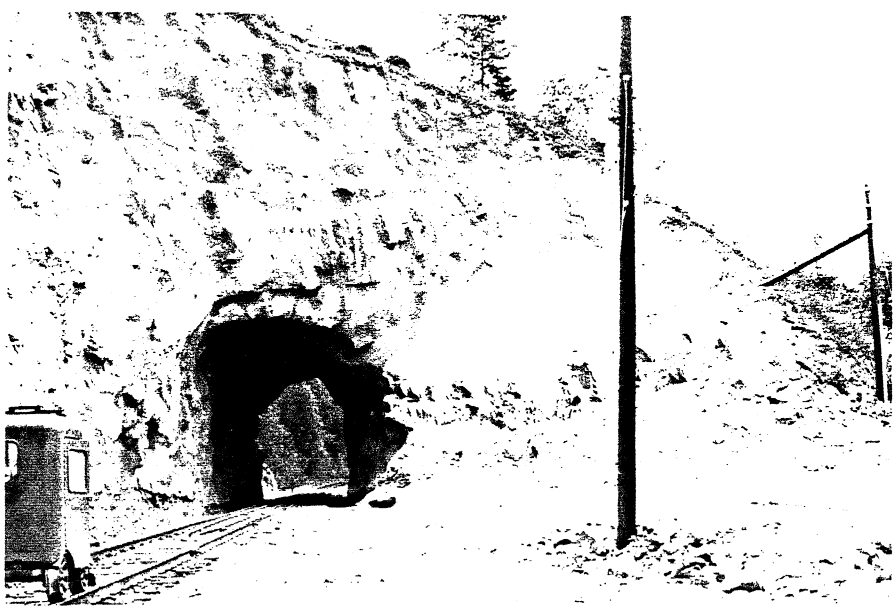

Photo 4. West portal after stabilization measures

In the spring the temporary mesh installation was removed and the west portal area was thoroughly scaled to remove rock loosened by frost action. Following scaling work 26-6 m. grouted bolts (15 mmØ) were installed above the tunnel opening on 3 m. centres. Around each bolt a 1 meter square steel fibre shotcrete bearing pad (100 mm thick) was applied followed by a galvanized washer plate and hexagonal nut. A final application of plain shotcrete was used to cover the entire west portal area so as to provide a structural membrane and protect the rock from further deterioration by weathering. Photograph 4 shows the west portal location after stabilization.

Trimming work was carried out on the south flank of the west portal and 3 m. vertical grouted dowels were installed perpendicular to the bedding planes to prevent further rock movement. Shotcrete was applied to the upper elevations of the south flank to stabilize ravelling rock conditions.

The entire tunnel crown was stabilized with 2.4 m. Swellex rock bolts installed in a ring configuration on 2 m. centres with each ring typically containing 7 bolts from springline to springline. Subsequent to bolting, drain tubes and drainage lines were installed at locations within the tunnel to tap off water from seepage zones and direct it down to the ditch elevation. Finally, steel-fibre shotcrete was applied to the tunnel crown and walls in thicknesses varying from 50 mm - 150 mm depending on rock conditions. The drainage system was also covered with shotcrete.

In total 121 m^3 of steel-fibre shotcrete was applied and 164-2.4 m. Swellex rock bolts were installed along the entire length of the tunnel. Nineteen 6 m grouted bolts were installed at the east portal in the same manner as those installed at the west end. Bolts were installed on a 3 m. grid and plain shotcrete was applied to the entire east portal area subsequent to bolting.

Since completion of the stabilization in the summer of 1985 the rock in the vicinity of the tunnel has been stable.

ACKNOWLEDGEMENTS

CONSULTING SERVICES

J. W. Stewart, P. Eng., of Stewart-EBA Consulting Ltd. formerly of Dolmage Mason and Stewart Ltd. has served as the technical advisor to CN Rail on the rock stabilization program since its inception in 1971 and has made a very valuable contribution to the success of the work.

LOCATION OF B.C.S.L. & B.C.N.L. APPENDIX 1