ROCK SLOPE ENGINEERING AND MANAGEMENT PROCESS ON THE CANADIAN PACIFIC RAILWAY

A.J. Morris, P.Geol., Engineering Geologist, Canadian Pacific Railway
D.F. Wood, P.Eng., Rock Engineer, David F. Wood Consulting Ltd.

ABSTRACT

The safe operation of a major railway line through mountainous terrain has been a continual challenge for the Canadian Pacific Railway (CPR) since the "Last Spikes" were driven in 1885 at Craigellachie, British Columbia, and at Jackfish, Ontario, completing the transcontinental railway. In 1976, an empty coal train hit rocks on the track, derailed and fell onto the Trans-Canada Highway near Spences Bridge, British Columbia, killing both engineers. Because of this accident, the Canadian Transportation Board ruled that an evaluation be undertaken of the stability of all rock cuts along the CPR and to prioritize sites where stabilization work was required. An initial slope inventory was conducted in both Western and Eastern Canada, detailed stability assessments were made of each site, priorities were established, and stabilization programs carried out.

Data collected during this evaluation became the basis for, what has become, a sophisticated database system used to store, evaluate and manage rock slope information obtained system wide. Considerable development in the method of slope prioritization has been accomplished, taking into account the potential hazard and consequences of a rock fall related incident together with the rock fall data and stabilization history for a given slope. The system used today by CPR to prioritize slopes combines an inspection rating with a required action and is the primary tool used in the CPR Rock Slope Engineering and Management Process. Components of the process include Planning, Inventory and Record Keeping, Inspection and Reporting, Stabilization Measures and Program Review.

INTRODUCTION

CPR manages rock slopes along over 750 miles of track from Vancouver to Calgary, over 650 miles of track in Northern Ontario and nearly 70 miles of track in upper New York State, incorporating a total of over 2500 man made excavated rock cuts throughout 20 subdivisions. A program of rock cut inspections, stability assessments and priority ratings for each slope is conducted on a regular basis by qualified rock slope specialists. Results generated from inspections together with all relevant historical information are used to plan short term (annual) and long term (over several years) stabilization programs. Once a list of work sites is finalized, cost estimates are made, contract specifications are written, and the stabilization work is tendered to pre-qualified private contractors.

The engineering and management of rock slopes on the CPR has been defined in an internal company Directive (1997) as "an organized process for the monitoring and investigation of rock slope behaviour, for the planning, design and implementation of rock slope mitigative measures, all for the purpose of contributing, at the lowest economic cost to the company's service requirements for safety, delivery and environmental protection." This is accomplished through the following processes:

- Planning – to identify short term and long term objectives
- Inventory and Record Keeping – of all rock slope information essential to effective management
- Inspection and reporting – including annual inspection of all slopes by professionals on a regular basis to determine priority ratings, and by track maintenance personnel during routine track inspections; construction inspections, rock fall inspections, detailed assessments and follow-up inspections.
- Stabilization measures – or mitigation undertaken through regular planned program construction work based on a priority system or due to emergencies or additional requirements obtained through detailed assessments.
- Program Review - undertaken annually to assess the program effectiveness and to identify possible improvements.

The key component of the process is the inspection rating system from which priority sites are identified and required actions are specified that define the time frame in which remedial work should be carried out.

INSPECTION RATING SYSTEM

History

The Canadian Pacific Railway initiated the first Priority evaluation of rock slopes along the mainline throughout British Columbia in 1976 after a Canadian Transportation Board ruling that such an evaluation shall be undertaken to prioritize sites where slope stabilization is required. This ruling came about after the deaths of two CPR locomotive engineers from a derailment caused by a rock fall at Mile 74.9 on the Thompson Subdivision. Golder Associates, geotechnical consultant engineers, were given the task of collecting pertinent information for each slope in order to establish priority stabilization sites and plan work programs.

The process used by Golder included the following four phases to establish Priority sites and the stabilization work required:

- Phase I - initial slope inventory;
- Phase II - detailed stability assessments for each site; slopes were prioritized using a rating system from A (highest probability of failure) to E (lowest probability);
- Phase III - detailed site specifications; and
- Phase IV - completion reports for the stabilization programs.

Data collected during this evaluation became the basis for, what is now, a sophisticated database system used to store, evaluate and manage rock slope information system-wide. Since 1976, information on rock fall incidents, mitigative measures, inspections and priority ratings has been collected annually on a consistent basis for British Columbia and Alberta, and since about 1994 for Ontario and New York State. Since 1994, considerable development in the method of prioritizing slopes has been accomplished, taking into account the potential hazard and consequences of a rock fall related incident. A system for statistical evaluation of rock falls is combined with previous work history and inspection data to aid in the planning for both short term and long term work programs. The current system used to prioritize rock slopes combines an inspection rating with a required action as described below.

Inspection Ratings and Required Actions

The observations made for each slope are used to assign an **inspection rating,** which describes the potential for rock falls, and to specify a **required action** which defines the time frame in which remedial work should be carried out. The assigned ratings are checked for consistency with previous year's ratings. Figure 1 illustrates the relationship between the rating and the required action.

Figure 1: Inspection Ratings and Corresponding Actions

		REQUIRED ACTIONS						
		Limit service Work within 1 month	Work in current year	Follow-up inspection	Work in 1-2 years	Lock-blocks/ ditch	Long term	No action
INSPECTION RATING	Urgent	X		X		X		
	Priority		X	X	X	X		
	Observe						X	X
	OK							X

Definition of Inspection Ratings and Required Actions

The observations made at each slope are used to assign an **inspection rating,** which describes the rock fall potential, and a **required action,** which defines the time frame for remedial work. The following is a description of the inspection ratings.

Urgent Rating

This inspection rating is restricted to sites where a potential rock fall hazard could cause a derailment and/or serious injury to personnel, and failure may occur within the next few weeks or months.

The possible actions following an **Urgent** rating are as follows. First, service below the slope should be limited, with this action normally being implemented as soon as practicable after the urgent condition is observed. The service limits could be a slow order, halting traffic, or having a watchman on site until the area is stabilized. A detailed follow-up inspection would then be carried out to determine stability conditions more accurately. A follow-up inspection would normally be carried out within one week to determine if the Urgent rating was justified and recommend an appropriate action. If stabilization work were required, it would be carried out within a specified time, which will not exceed one month, depending on the severity of the condition. If there is an adequate ditch at the site, the work may be limited to ditch cleaning.

Priority Rating

The **Priority** rating is used at sites where there is evidence of movement or change in conditions from the previous year's observations. It is also used where the volume of potential failure material is large enough and the material unstable enough that it could reach the tracks and cause derailment or injury.

There are three possible actions following a **Priority** rating.

- Firstly, the site could be scheduled for work that could be added to the current year's stabilization program; the required work may be limited to ditch cleaning.

- Secondly, a detailed follow-up inspection could be carried out within about three months to more accurately assess stability conditions and recommend an appropriate course of action.

- Thirdly, the site could be added to the list of sites considered for stabilization work over the following 1 - 2 years.

Observe Rating

The **Observe** rating is used at sites where potential instabilities exist that could impact the tracks, and where some deterioration in stability conditions is noted, such as loosening of blocks or minor raveling. Usually this specific area will be observed in each subsequent inspection for a change in condition. Where possible, a photograph of the potential instability should be taken each year from the same location to help document and assess any changes.

There are two possible actions following an **Observe** rating. First, no further action may be required. Second, the site could be added to the list of sites considered for long term stabilization. Long-term sites require a substantial stabilization program to provide long term protection against rock falls. Typical work might include a rock fall catch ditch excavation, extensive rock bolting, shotcreting, slide fence installations, or Lockblock installations.

OK Rating

This inspection rating is used at sites where no potential instability could impact the tracks, or, where some slope movement is observed but there is minimal risk of failure at present. The only action arising out of this rating is No Action.

PLANNING

On an annual basis, meetings are held between CPR Geotechnical Staff and Consultant Specialists involved directly in program management, generally soon after annual rock slope inspections have been completed, to plan both short-term stabilization requirements for the following year's program as well as long-term or 4 to 5 year plans for stabilization projects. Sites requiring short-term stabilization work by contract during the upcoming year are selected from those meeting one or more of the following criteria:

1) Any sites that were included in the previous year's work program but were not completed either for budgetary or operational reasons;
2) Priority sites identified during the annual inspection two years prior, where action was recommended in 1-2 years that were not included in the previous year's work program;
3) Priority sites identified during the previous year's annual inspection where action was recommended in 1-2 years;
4) Any other Priority site identified either during previous inspections or because of recent Follow-up inspections or detailed site assessments of recent rock fall locations; or
5) Any sites rated as "Follow-up" during the current year's inspections that after field investigation were re-rated as current year sites.

Sites for which stabilization requirements cannot be determined without detailed geotechnical investigations, surveying or design work are rated during the inspection process as "Long Term". The required design and stabilization measures cannot usually be completed in one field season because of following reasons:

1) The required work involves several construction stages;
2) Detailed design investigations must be completed prior to any construction;
3) Operational restraints such as availability of track time, track personnel are restrictive; or
4) Budgetary restraints prevent completion.

In addition to site selection, considerations such as personnel requirements and available budgets are planned on an annual basis.

INVENTORY AND RECORD KEEPING

The primary tool used for managing all relevant rock slope information is the CPR rock slope database which has been built upon the original 1976 inventory of all CPR rock cuts. In 1985, a dBase database was used to track rock fall records as part of the rock slope stabilization program. In 1993, the database was converted to Paradox and expanded. In addition to rock fall records, it now includes descriptions of rock cuts and tunnel portals, annual inspection observations, slope ratings and required actions and summaries of stabilization work performed. The database is continuously up-dated as new information becomes available. By organizing the data in a format that can be easily searched and sorted, the database has become an integral part of the planning and management of the stabilization program. Once inspections have been completed, the most recent Priority ratings are used in the planning of short-term and long-term stabilization programs.

The database is updated throughout a given year with the following information:

1) Descriptions of each site, identifying its "type" as either a slope, tunnel, bridge, retaining wall etc.
2) Rock fall reports from each subdivision, system wide. Figure 2 shows the number of rock falls for 1998, as well as over a five year period and a 24 year period for five subdivisions.
3) Annual inspection report information for each subdivision, including Priority ratings, required actions and comments for every documented rock cut in every subdivision.
4) Results of Follow-Up inspections, which could change the Priority rating assigned during an annual inspection.
5) Construction and stabilization information including actual work completed or not completed for each site where current year stabilization work was planned.

INSPECTION AND REPORTING

Annual Inspections

A schedule for the annual rock slope inspections across the CPR system is drawn up very early in the year so that the appropriate arrangements can be made. Inspections are made by helicopter in those subdivisions having the highest and most active slopes as well as along the track from a high rail vehicle. Other subdivisions are inspected from the track only. Most mainline and active rock fall locations are inspected annually, while other, less active slopes are inspected once every two years.

Information is gathered for each rock cut using a database-generated rock slope inspection form. Using the database, information including the last recorded rock fall, geology notes, cut height, the most recent Priority rating, required action and the last year stabilization work was carried out is shown on the form, see Figure 3. Space is provided for observations, an inspection rating and required action. A photographic record is also kept of rock cuts with evidence of instabilities from year to year, allowing for visual comparisons over time.

Figure 2: Total Reported Rock Falls B.C. and Prairie Districts 1998

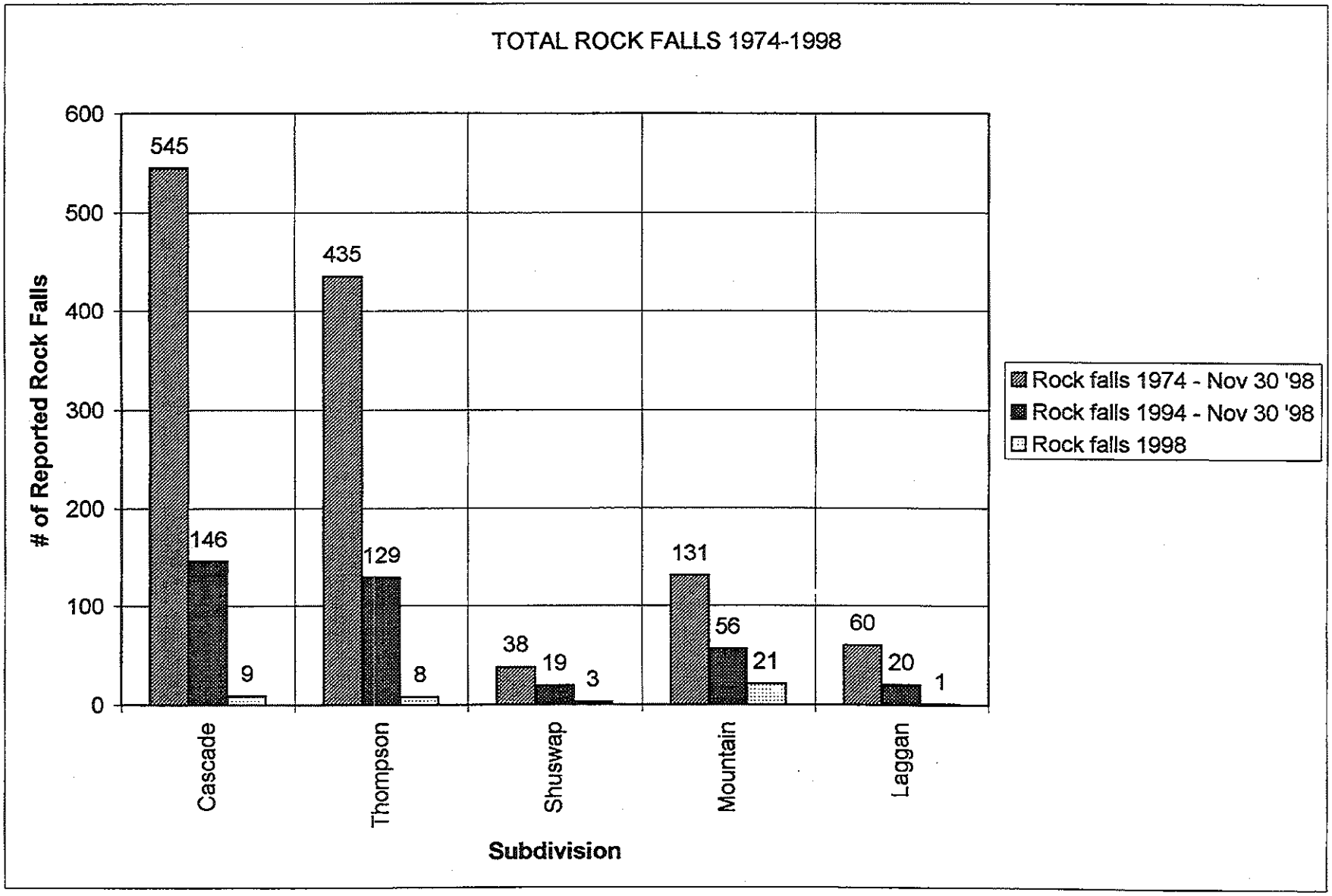

Figure 3: Rock Slope Inspection Form

ROCK SLOPE INSPECTION

Inspected by: Subdivision: Mountain Pg.: 1 Inspection Date: April 6, 1999

Mile	Site Type	Height (m)	Site Records	Observation	Insp. Rating	Required Action
31.90	☐ Cut ☐ Nat. Slope ☐ Fill ☐ Slide Fence ☐ Drainage ☐ Wall ☐ Tunnel ☒ Bridge	Cut Max. Cut-N: Cut-S: Nat. Slope:	**Last Rock Fall:** Last Work Year: 1997 Cut Notes / Geology: *Shale – low strength, horizontal bedding with spacing of ¼"-2".* ***1998 OK No Action*** ***Due to the nearly horizontal orientation of shale beds, small pieces tend to occasionally drop from crown.***	**Photo:**	☐ Urgent ☐ Priority ☐ Observe ☐ OK	☐ Follow-up ☐ Current Year ☐ Limit Service ☐ 1-2 Years ☐ Long-term ☐ Lockblocks ☐ Clean Ditch ☐ No Action
31.00	☐ Cut ☐ Nat. Slope ☐ Fill ☐ Slide Fence ☐ Drainage ☐ Wall ☐ Tunnel ☐ Bridge	Cut Max. *180* Cut-N: Cut-S: Nat. Slope:	**Last Rock Fall: 1986** Last Work Year: 1993 Cut Notes / Geology: *Inspect Mile 30.9 – 31.1. Potential of large rock block falls is high. Frequent rock falls – rock and mud flow at Mile 31.0 took out track.* *Bedded phyllite rock. Some hard layers and blocks.* ***1998 Observe Long-term*** **West Portal: excavate rock starting at tunnel to create catchment area, and extend excavation to the west into talus area. In 1997, catchment berm created in talus.**	**Photo:**	☐ Urgent ☐ Priority ☐ Observe ☐ OK	☐ Follow-up ☐ Current Year ☐ Limit Service ☐ 1-2 Years ☐ Long-term ☐ Lockblocks ☐ Clean Ditch ☐ No Action
31.20	☐ Cut ☐ Nat. Slope ☐ Fill ☐ Slide Fence ☐ Drainage ☐ Wall ☐ Tunnel ☐ Bridge	Cut Max. *30* Cut-N: Cut-S: Nat. Slope:	**Last Rock Fall: 1992** Last Work Year: 1993 Cut Notes / Geology: *Tunnel portal plus 45 m (150 ft). Periodic rock falls. Adverse jointing near top. Potential toppling failure.* *85 deg. (120 deg) 75 deg (030 deg) jointing. Horizontally bedded phyllite rock.* ***1996 Observe Long-term*** ***A" follow-up inspection. Long-term: deepen ditch and scale***	**Photo:**	☐ Urgent ☐ Priority ☐ Observe ☐ OK	☐ Follow-up ☐ Current Year ☐ Limit Service ☐ 1-2 Years ☐ Long-term ☐ Lockblocks ☐ Clean Ditch ☐ No Action

A target date for completion of inspection reports for mainline subdivisions has recently been set at two weeks after the inspection. This is to ensure that the inspection results can be distributed to track personnel in a reasonable time if priority or urgent sites were observed, and to give CPR District personnel adequate time for planning stabilization programs.

A typical report includes a definition of inspection ratings and required actions; tables of inspection ratings, required actions and observations for each site, identified by subdivision and mileage; descriptions of each site with priority ratings; selected site photographs, summary of rock falls and long term stabilization sites.

Construction Inspections

During the course of annual contract stabilization work, inspections of the work progress and site conditions are carried out on a regular basis either by geotechnical consultants or by CPR geotechnical staff. Stability requirements are determined and recommendations made for stabilization measures such as scaling, rock bolt or rock dowel installation, concrete buttressing or shotcrete etc. Formal site reports are required for these inspections.

In all CPR rock slope stabilization contracts, the contractor is required to complete a "Daily Work Report" form, summarizing the personnel, equipment and materials used for work during a particular day. The CPR representative on site (usually the flagman) also supplies information on actual track time available and hours worked on the track that day. At the completion of the work at a particular site, this information is used to summarize the work completed in a "completion" report.

Rock Fall Report Inspections

Track maintenance personnel patrol the track routinely. They report any signs of recent slope activity if observed. A CPR rock fall report is generally submitted if a rockfall is discovered on or adjacent to the track and there is concern that there may be additional instabilities. Similarly, when rockslide detectors or rockfall detectors are triggered and repaired by Signals and Communications personnel, a report is submitted. An example of a typical rock fall report is shown in Figure 4.

Provision is provided on the rock fall report form to request an inspection within a specified time frame. Inspections are carried out either by CPR geotechnical staff or consultant specialists. Once the inspection has been made a formal site inspection report is required to be submitted to CPR describing observations and recommended actions.

Figure 4: Rock Fall Report

SEND TO: MOR0007,GOL1010 COPIES: MAC0015,OM01220,MTM,JON

REPORT OF ALL ROCK FALLS, ROCK SLIDES, MUD SLIDES & SNOW SLIDES WHICH CAUSE OR MAY CAUSE: A DERAILMENT, DAMAGE, INJURY OR DELAY TO ANY TRAIN, ROLLING STOCK, EQUIPMENT, WORK SECTION/CREW, EMPLOYEE OR OTHER PERSON.

1. DISTRICT: B.C. District
2. SUBDIVISION: Cascade
3. MILEAGE: 10.50
4. DATE: November 22/23, 1998
5. TIME: After 13:00 Nov. 22/98.
6. WEATHER CONDITIONS:
 a) AT TIME OF OCCURRENCE(Snow,Rain,Dry,Temp) Moderate rain, 4 c.
 b) 24 HRS.PRIOR TO OCCURRENCE(Condition,Temp)Heavy rain, 4 c.

7.a) TYPE OF FALL/SLIDE(Rock,Mud,Tree,Snow) Rock.
 b) LOCATION OF FALL/SLIDE(Track,Ditch) North side, edge of ballast section.
 c) SIZE OF FALL/SLIDE(Feet,Cu.Yd.,Tons) 5 boulders, total 3 cubic metres.
8.a) DELAYS TO TRAIN MOVEMENTS(Hrs.,Mins.) Nil
 b) HAS A SLOW ORDER BEEN PLACED? ( ) Y (X) N
 c) IF YES, WHAT SPEED?

9.PARTICULARS OF ANY DAMAGE TO TRAIN/INJURY TO PERSONS: (X) nil
10.a) TIME TO CLEAR FALL/SLIDE(Hrs.,Mins.) N/A
 b) EQUIPMENT USED (BTMF forces,Contractor)
11.ORIGIN OF SLIDE/FALL(Loc'n.,Ht.above track) Boulders dislodged from tree line approximately 100 ft. up slope.
12.a) IS THERE MORE LOOSE MATERIAL ON THE SLOPE? (?) Y (?) N
 Two boulders at tree line that may eventually fall as the soil is eroded.
 b) IF YES, HOW MUCH (Cu.Yd.,Tons) Approx. 2 cubic metres total.
13.a) IS THERE A CATCHMENT DITCH AT THE SITE? (X) Y ( ) N
 Natural depression.
 b) IF YES, HOW WIDE AND DEEP? Roughly 14 ft. wide x 2 ft. deep.
 c) HAS THE DITCH BEEN CLEANED OUT? ( ) Y ( ) N
 Will use a backhoe to place fallen rock and ditch a burm, sometime this week.
 d) IS THERE A SLIDE FENCE AT THE SITE? ( ) Y (X) N
 e) IS THERE A RETAINING WALL AT THE SITE? ( ) Y (X) N
14.IS AN IMMEDIATE SITE INVESTIGATION REQURIED? ( ) Y ( ) N
 Mr. Frank Seki inspected, Monday Nov. 23/98.
 IF NO, IS AN INVESTIGATION REQUIRED IN 1WK?( ) 1MO?( ) 1YR?( )

COMPLETED BY:		INFORMATION PROVIDED BY:	
Name:	Victor L. Tome'	Name:	Frank Seki
Title:	A.T.M.S.	Title:	Geotechnical Engineer,
Location:	Haig B.C.	Location:	Golder Associates
Date:	November 23, 1998	Date:	November 23, 1998

Detailed Assessments and Follow-Up Inspections

Detailed stability assessments and follow-up inspections are generally required when more field information is needed to further evaluate the inspection rating of a site and to finalize stabilization design requirements. These inspections are usually carried out by senior engineering personnel or specialists. The results of a follow-up inspection could lead to a re-rating of a slope. A formal report is required for all follow-inspections.

All of the inspections described above will have an effect on the final site selection for a given year's stabilization program.

STABILIZATION MEASURES

Mitigation or stabilization measures are determined for each of the priority sites selected for work either as part of the annual, short-term program or a long-term program, which may take several years to complete. Sites rated as Urgent are generally not considered part of program work, as more immediate measures are required.

Short-Term Programs

Rock slope stabilization work on an annual basis is considered a short-term program. Work sites are selected using the Priority Ratings as described above, stabilization methods chosen and cost estimates made for the work in each subdivision. An estimate is made of the number of work days required and the materials needed at each site. Annual contracts are tendered for work in each CPR District based on the estimated quantities. Operating from an annual budget, all costs for Engineering and CPR's own forces must be estimated based on the amount of stabilization work in the year's program. Figure 5 shows part of a typical estimating spreadsheet describing the work required at each location for a CPR annual work program.

Typically, the types of stabilization measures employed during an annual work program include hand scaling, machine scaling, rock bolt and dowel installation, shotcreting, concrete buttressing, Lockblock wall construction and ditch excavation.

Long-Term Programs

Rock stabilization programs considered long-term are generally those that involve mitigative work over several years due to the size and cost of the recommended measures. They are sites that require careful planning, engineering design and high level approvals but are primarily aimed at eliminating a potential high hazard location to improve operating conditions.

Typical types of long-term stabilization work include major ditch widening and slope excavation, rock fall catchment fences, rock fall sheds or major rock bolting and shotcreting.

PROGRAM REVIEW

An annual audit of the rock slope engineering program is conducted to evaluate how each of the processes was implemented across the system. Tables summarizing the effectiveness of inspections, inspection ratings, rock fall inspections, construction inspections, follow-up inspections, construction activity and status of long term stabilization sites are produced and used as planning aids for the following year.

Using this review process, full closure is brought to the management process, allowing for the next year's rock engineering program to proceed with all of the data and benefits accrued from the previous years' program. This process becomes a built-in procedure of monitoring and continuous improvement to ensure that the Canadian Pacific Railway's rock slopes are managed effectively and efficiently.