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RAILWAY GROUND HAZARD RISK SCENARIO: RIVER EROSION: EARTH-SLIDE

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Abstract

A risk scenario is a chain of events that leads to loss with an associated frequency and severity. The paper demonstrates the utility of describing the risk associated with railway ground hazards in terms of a risk scenario using the river erosion: earth-slide (RE:ESl) risk scenario, one of the highest loss complex risk scenarios faced by railways in BC, Canada. Two CNR case examples, the Ashcroft Mile 50.9 Landslide on the Thompson River and the Skeena Mile 28 Landslide on the Skeena River, are used for this purpose. The risk scenario at Ashcroft Mile 50.9 is shown to start with channel degradation that leads to a first earth-slide hazard classed as a reactivated, multiple rotational earth-slide that leads to a second more severe earth-slide hazard classed as a reactivated, retrogressive, compound earth-slide. The risk scenario at Skeena Mile 28 is shown to start with 2 hydrotechnical hazards, a major stream shift hazard and a channel degradation and scour hazard that subsequently lead to the third hazard in the scenario, a rapid reactivated retrogressive rotational earth-slide. The exercise shows that representing railway ground hazards in this context provides a powerful predictive tool in terms of mechanical, temporal and spatial attributes that facilitates an effective risk management strategy.

Résumé

Un scénario de risque se défini par une série d'événements menant à des pertes qui sont associées à une fréquence et un degré de sévérité. Cet article montre l'utilité de décrire le risque associé aux aléas mouvements de sols reliés aux chemins de fer en terme de scénario de risque en utilisant le scénario d'érosion des berges d'une rivière: glissement de terrain (RE:ESl). Celui-ci constitue l'un des scénarios complexes de risque impliquant les plus grandes pertes pour les chemins de fer de la Colombie Britannique, Canada. Deux études de cas du CNR sont utilisées dans cet article, c'est-à-dire le glissement de terrain de Ashcroft au mile 50.9 le long de la rivière Thomson et le glissement de terrain de Skeena au mile 28 le long de la rivière Skeena. Le scénario de risque de Ashcroft présente tout d'abord une dégradation de la rivière menant à un premier type de mouvement classé comme un glissement rotationel multiple réactivé menant lui-même à un second type de mouvement plus sévère classé comme un glissement composé rétrogressif réactivé. Le scénario de risque de Skeena est d'abord initié par deux aléas hydrotechniques, c'est-à-dire un changement majeur de la position d'un ruisseau et une dégradation de la rivière, ainsi qu'un dragage naturel du fond de la rivière. Ces phénomènes hydrotechniques mènent subséquemment au troisième aléa du scénario, c'est-à-dire un glissement rotational rapide rétrogressif réactivé. Cet exercice montre que la représentation des aléas mouvements de sols reliés aux chemins de fer dans ce contexte fourni un outil de prédiction puissant, en terme d'attributs mécaniques, temporels et spatiaux, facilitant une stratégie effective de gestion du risque.

1 INTRODUCTION

A risk scenario is defined in CAN/CSA-Q850-97, "*Risk Management Guide for Decision Makers*" (CSA 1997), as a sequence of events with an associated frequency and consequence. Risk scenarios associated with railway ground hazards may be complex, comprising a sequence of interrelated ground hazard events. The operating integrity of the railway may be threatened less by an initial hazard event than by subsequent events in a risk scenario.

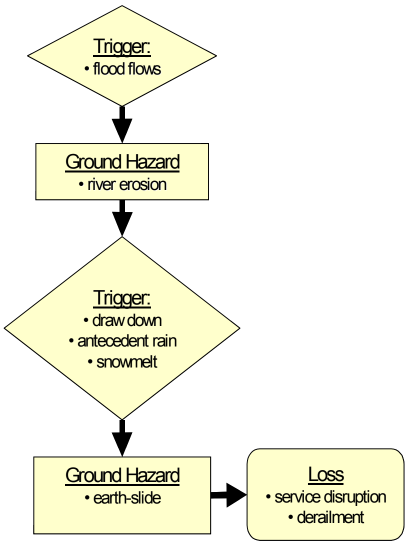
An understanding of risk scenarios is essential to the management of consequent losses. The value of identifying risk scenarios is summarized as follows:

- The entire risk exposure is scoped out and attention is only drawn to the relevant aspects of the risk.
- Provides a tool for searching out similar risk scenarios and hazards.
- Intervention is focused at critical links in the chain thereby optimizing risk control efforts.
- Provides a powerful predictive tool by mapping out the potential future chain of events in terms of mechanical, temporal and spatial attributes.

The objective of this paper is to demonstrate this value using two case examples of the river erosion: earth-slide (RE:ESl) risk scenario. This risk scenario is one of the more prevalent complex risk scenarios encountered by railways in British Columbia. It is estimated that situations falling into this category of risk scenario cost Canadian National Railway (CNR) $1.6 million in mitigation costs in 2001 and 2002.

Fig. 1 illustrates a typical RE:ESI risk scenario. Typically, triggered by flood flow in the river, this scenario initiates with the loss of erodible material at the toe of a slope due to river scour, a hazard event. This event may result in an over-steepened slope condition below the rail grade

Figure 1: Flow chart of a typical river erosion: earth-slide (RE:ESI) risk scenario



raising the likelihood of an earth-slide (Cruden and Varnes, 1996), a second hazard. Intense rainfall, a triggering event (Wieczorek, 1996), may subsequently occur at the hazard location filling tension cracks and raising pore pressures. Driving forces are increased and effective stress is reduced resulting in a rapid earth-slide. This earth slide hazard poses a significant risk to train traffic as the track roadbed may be involved in the slide.

2 ASHCROFT MILE 50.9 LANDSLIDE

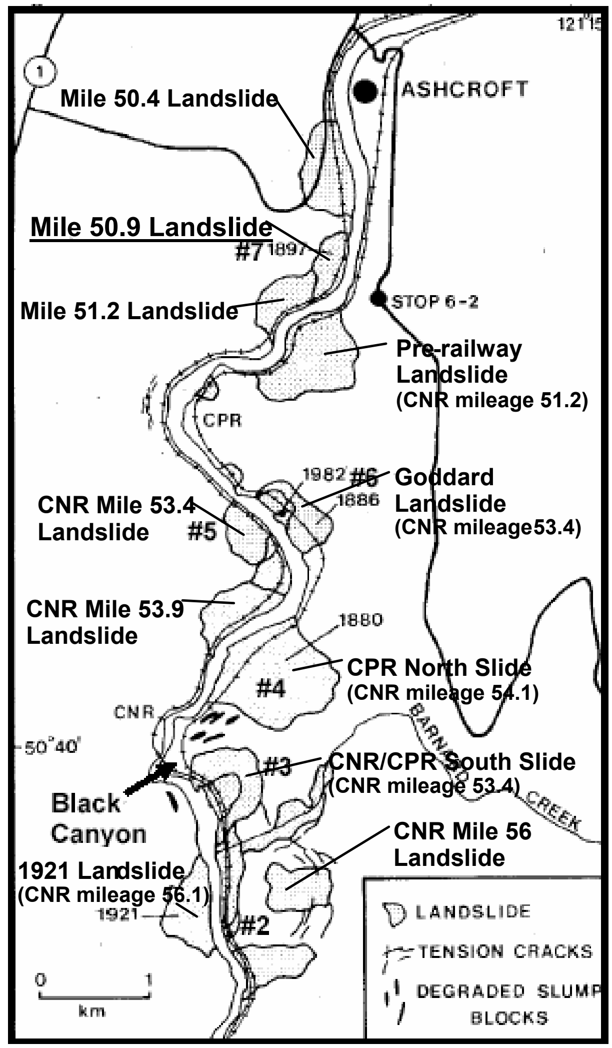
2.1 Setting

The first case history selected to illustrate the utility of identifying the RE:ESI risk scenario is located at Mile 50.9 of CNR's Ashcroft Subdivision which carries freight and passenger service between Kamloops and Boston Bar.
This RE:ESI risk scenario involves a large active earth-slide situated on the right bank of the Thompson River approximately 2 kilometres south of Ashcroft in south-central BC. The CNR mainline track traverses over the active toe area of this landslide while CPR's mainline track is on the opposite riverbank.

The Ashcroft Mile 50.9 Landslide is one of several large earth-slides located on both banks of the 13-kilometre reach of the Thompson River downstream of the Town of Ashcroft (Fig. 2). The landslides have been problematic to both CPR and CNR since railway construction around the end of the 19th century. The nature and character of these landslides is well documented with the earliest paper by Stanton (1898) and the most recent by Porter et al (2002).

The landslides formed as part of the rapid degradation of the Thompson River in post-glacial times through extensive glacial lake deposits that filled the pre-glacial valley (Holland 1976). With the thalweg still well above pre-glacial valley bottom levels over most of its length (NWH, 1977), the degradation is expected to continue. As a result, the cyclic interaction between river erosion and earth-slides is also expected to continue and thus represents a risk to railway operations.

Figure 2: Location plan of Mile 50.9 Landslide and landslides south of Ashcroft (after Porter et al, 2001)

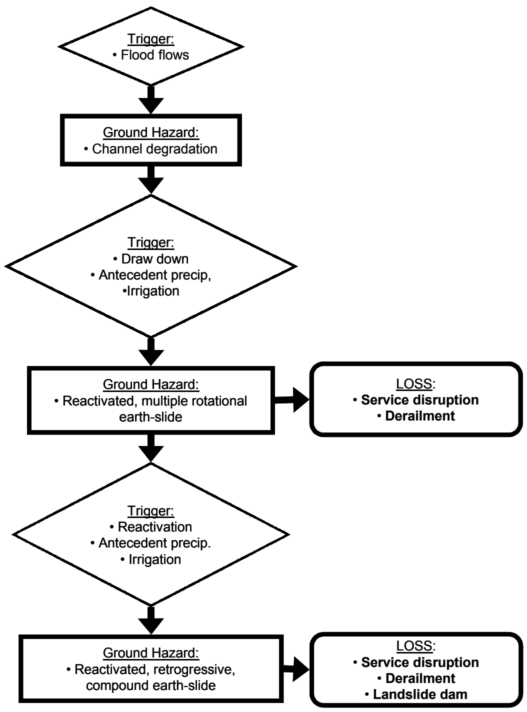


Recently attention was drawn to the Mile 50.9 landslide by discovery in February 2001 of 100 metres of arc-shaped tension cracking in the existing rock berm below track level on the right bank of the Thompson River. This prompted a detailed geotechnical and hydrotechnical investigation and monitoring program aimed at assessing the likelihood and consequence, the risk, represented by this hazard. Following are the results of that assessment presented in the context of the RE:ESI risk scenario.

2.2 Summary of Ashcroft Mile 50.9 RE:ESI Risk Scenario

The RE:ESI risk scenario at Mile 50.9 Ashcroft is summarized in Fig. 3. The first ground hazard in the scenario is a hydrotechnical river erosion hazard specifically classed as channel degradation. This hazard event is triggered by flood flows in the river that occur in May and June of a flood year. Normally the channel

Figure 3: Flow chart depicting the Mile 50.9 Landslide Risk Scenario



degradation does not immediately cause track failure but rather generates the conditions for a geotechnical landslide hazard classed as a reactivated multiple rotational earth-slide. These hazard events are triggered by drawdown of the river level in the fall and winter months; incremental increases in pore pressure brought on by long term antecedent precipitation or irrigation; or intense rainfall filling tension cracks. This first earth-slide hazard can and has resulted in track failure, which may lead to a significant service disruption or derailment. The more serious secondary earth-slide hazard generated by the reactivated multiple rotational earth-slide event is the retrogressive compound earth-slide hazard. This hazard event can be triggered by either stress relief resulting from reactivation of the first earth-slide hazard event or by incremental increases in pore pressure brought on by long term antecedent precipitation or irrigation. Although unlikely, the high speed and mobility associated with the secondary earth-slide hazard has the additional potential of forming a landslide dam. Following is a description of each of the components of this risk scenario starting with the earth-slide hazards.

2.3 Ashcroft Mile 50.9 Earth-slides

The Cruden and Varnes (1996) landslide terminology is used in this exercise as it provides for the description of the features of landslides relevant to their classification for avoidance, control, or remediation. Using Cruden and Varnes the first earth-slide hazard at mile 50.9, and likely most of the others shown in Fig. 2, was a reactivated, multiple rotational earth-slide. The concern is that the potential second earth-slide hazard is a reactivated, retrogressive, compound earth-slide. Concern arises due to the speed and mobility associated with compound earth slides that would disrupt train service and might partially or completely block the river forming a landslide dam. This is known to have occurred at other landslides within this reach such as the historic CPR North Slide that dammed the Thompson River for 44 hours in 1880 (Evans 1986). Reactivation of the multiple rotational earth-slides has also proven to be moderately disruptive by the reactivation of the Goddard Slide in September of 1982 that put the CPR out of service for 6 days.

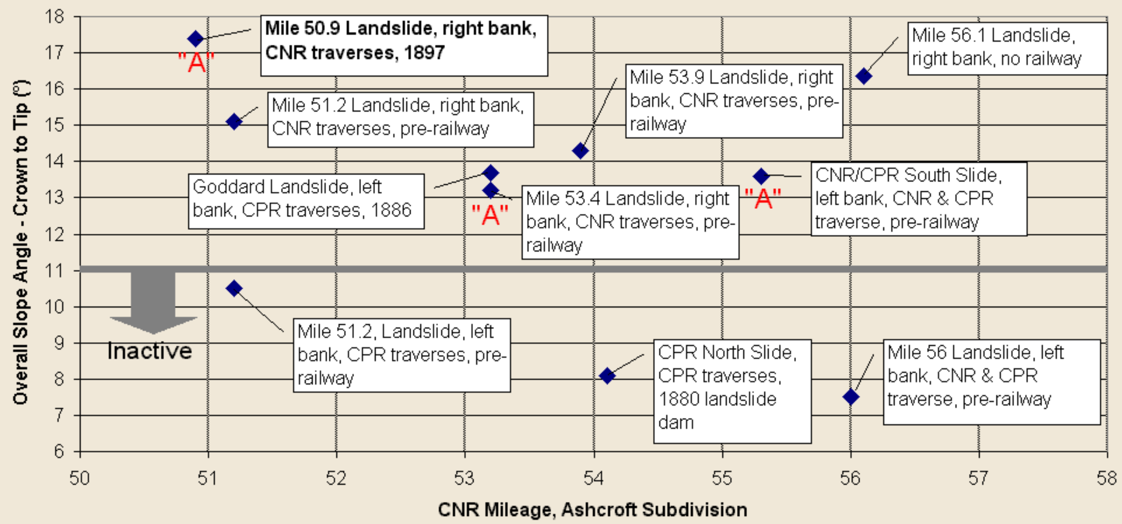
The adjective “compound” refers to a mode of sliding intermediate between rotational and translational (Cruden and Varnes,1996). In the case at Mile 50.9, high plastic glaciolacustrine clay and silt are found at depth. Compound slides often indicate the presence of a weak layer at depth and such zones often control the location of the surface of rupture.

With the compound mode of sliding there is commonly an abrupt decrease in down slope dip of the surface of rupture. Kinematically, this results in minor uphill dipping scarps in the displaced masses and the subsidence without rotation of blocks of displaced material that form depressed areas or grabens. The Rycroft Landslide Dam described by Cruden et al (1993) provides a good case example of this feature. It is suggested that the formation of the uphill facing scarps (see Fig. 6) introduce additional driving forces that are a contributing cause of the increased speed and mobility exhibited by these earth-slides in the secondary compound mode of movement.

One indicator of the stage of evolution of compound earth-slides is the overall slope angle measured from the crown to the tip of the landslide. Cruden et al (1993) showed that the overall slope angle for fully mature compound earth-slides on the Saddle River approximated the residual friction angle (ϕ_R) of the weak controlling material at depth, which in that case was in the order of 8°. According to Porter et al (2002) the ϕ_R of the glaciolacustrine deposits at the Mile 50.9 Landslide, are in the order of 11° to 12 °.

Consequently slope angles for the major landslides along reach of the Thompson River have been measured and presented on Fig. 4. Landslides that are known to be active since the 1997 flood event are noted with an “A” in Fig. 4. The first observation is that the landslides that have a slope angle below 11° namely at CNR mileages 51.2 (left bank), 54.1(left bank) and 56 (left bank), correspond to those landslides that have been observed to have undergone secondary compound movements and are now reactivated, retrogressive, compound earth-slides. These landslides all have low slope angles, have no recent activity, have pushed the river over and formed a meander away from them and show air-photo evidence of uphill-facing scarps. Of note also is that each of these landslides has corresponding landslides on the opposite bank of the river with slopes significantly above 11°.

Figure 4: Overall Slope Angle of Landslides Downstream of Ashcroft on the Thompson River



Landslides with slopes greater than 11°, including Mile 50.9, have sharper scarps inferring they are younger in their evolution and active. At CNR mileage 53.4 the two opposing landslides appear to have balanced themselves off at a slope angle of around 13.5°, still 2.5° above 11°. In the context of this paper, the most significant observation is that the Mile 50.9 Landslide has the highest slope angle at 17.5°. It is concluded from this that the secondary compound earth-slide movement has yet to occur at this location. This is not to say that the secondary movement is likely in this case as there are a number of unknown conditions that may preclude it but nonetheless the possibility warrants significant attention.

The triggering event for the reactivated, multiple rotational earth-slide, using Wieczorek's (1996) definition, is inferred to be draw-down conditions brought on by very low river levels in the Fall or Winter months following flood and scour events. The correlation between river level and slide movements is highlighted in Fig. 5. Movement rates measured on the rupture surface in the toe area of the Mile 50.9 Landslide are plotted with river levels from April to October of 2001.

A cross section of the slide is shown in Fig. 6. Failure surfaces are interpreted from slope indicator readings and known scarps. Surface #4 is inferred from truncated slip-circle search, 45°+ϕ/2 scarp dip and an arc shaped depression observed behind the existing crown. Piezometric levels are taken from instrumentation near the toe of the slope and extrapolated back to mimic ground surface. Analysis indicates that surfaces #1 and #2 are essentially meta-stable. The stability of surfaces #3 and potential surface #4 are relatively higher provided the glaciolacustrine clay remains undisturbed. When the shear strength in the glaciolacustrine clays is dropped from ϕ_P'=19° and c'=20 kPa to the residual strength of

Figure 5: Mile 50.9 Landslide: Toe block movement rates versus river level during 2001.

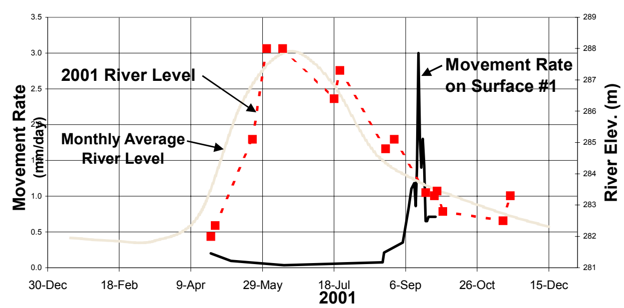
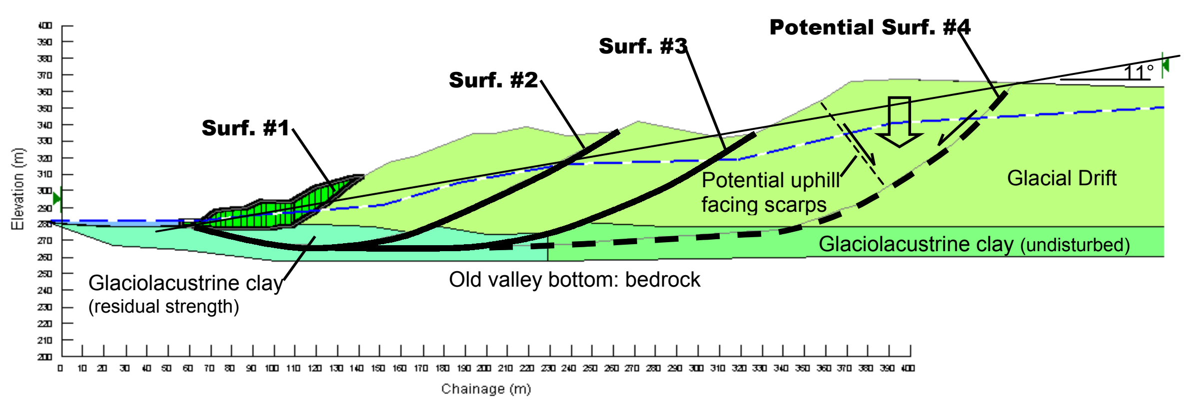


Figure 6: Mile 50.9 Landslide general surface stability back-analysis section.



ϕ_R'=11° and c'=0 along surface #4 in the analysis there is a 19% drop in sliding resistance. This condition could be triggered were there excessive movements and stress release on surfaces #1, 2 or 3 (strain weakening). Another possible trigger for movement on surface #4 is an incremental increase in pore pressure in the glaciolacustrine deposits resulting from events such as high antecedent precipitation or up slope irrigation.

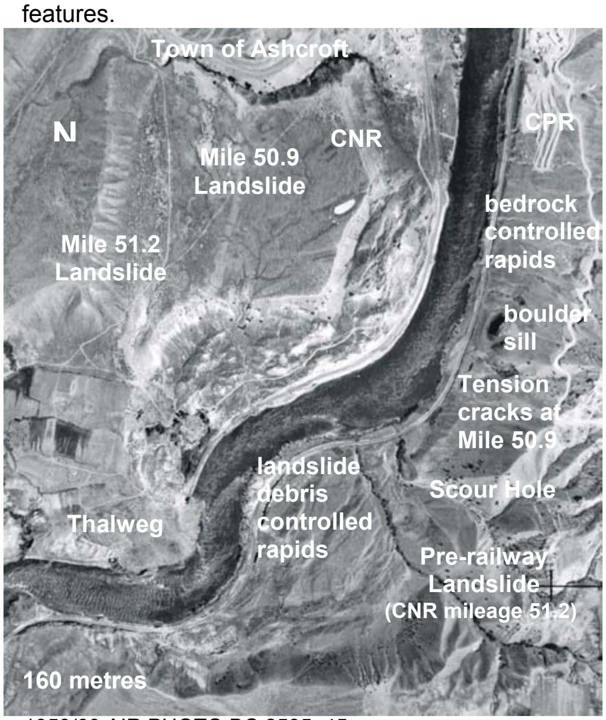
2.4 Ashcroft Mile 50.9 River erosion

Fig. 7 illustrates the general arrangement of the landslide and river features in the vicinity of the Mile 50.9 Landslide. To understand the river erosion processes in proximity to the Mile 50.9 landslide it is necessary to examine the river morphology.

The river is generally 150 m wide and up to 3 m deep at low stages and 4.5 m or more above low stage level during flood stage (NWH, 1977). The average gradient of the river is 0.0014 m/m. The bed consists generally of cobbles and boulders overlying gravel, consolidated silt and till, with numerous boulder rapids and some rock outcrops. The natural channel banks are generally covered with cobbles and boulders, but have been modified considerably in many places by landslides and by railway construction and maintenance. The plan form of the river channel can be described as consisting of irregular entrenched meanders approximately 2.1 kilometres in wavelength. There is virtually no flood plain.

The river is relatively straight in its approach to the Mile 50.9 Landslide, followed by a moderate rightward bend. The toe of the landslide is on the inside of this bend. In these circumstances, it would normally be expected to find the thalweg located adjacent the left bank whereas,

Figure 7: Location of landslide and river hydrology features.



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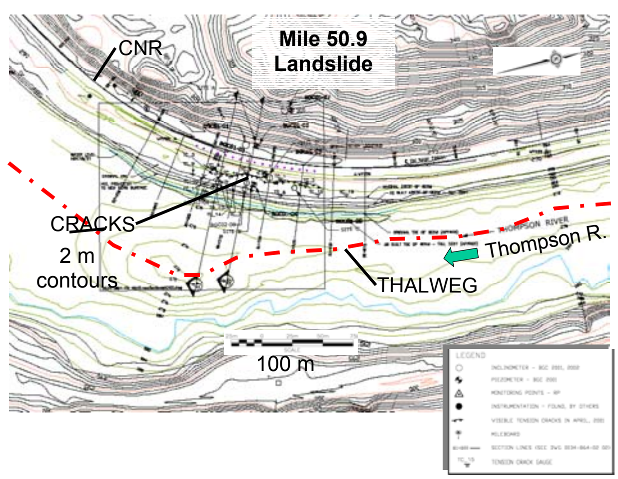
as shown in Fig. 8, the thalweg is located close to the right bank. The reason for this is apparent from Fig. 7. Upstream, the rapids are controlled by shallow bedrock on the left bank of the river and, opposite the landslide; the left half of the channel contains a series of boulder bars. This continuous zone of roughened bed on the left side of the channel likely forces flow and the thalweg to the right half of the channel.

Immediately downstream of the tension cracks the river appears to have scoured out a 6 metre deep hole towards the middle of the channel (see Fig. 8). Further downstream, a pre-railway landslide originating from the left bank has evidently pushed the channel significantly to the right and caused the landslide debris controlled rapids noted on Fig. 6. It is likely this secondary compound earth-slide event resulted in a pre-railway landslide dam that flooded a large area upstream. Once breached, the river down cut into the right bank over-steepening the slope. This probably triggered the activation or reactivation and possible retrogression of the Mile 51.2 and 50.9 multiple rotational earth-slides, the first movement type. The 6-metre deep hole in the thalweg immediately downstream of the Mile 50.9 Landslide may be a remnant of the channel that existed before the pre-railway landslide.

Apparent from the rapids that wrap around the slide debris of the prehistoric landslide (noted on Fig. 7) and the 6 metre scour hole upstream of the rapids, the channel is actively degrading into slide debris which came from both sides of the river and is attempting to reestablish its pre-slide level. This process of channel degradation (Savigny et al, 2002) is expected to continue and thus will result in the erosion of material at the toe of the Mile 51.2 and 50.9 landslides. History supports this assessment as movements were observed and remediation required at the location of these landslides in the years following significant flood events most notably the 1921, 1948, 1972, 1997 and 1999 floods. Channel degradation, a ground hazard event, is thus the key preparatory factor to the earth-slide hazard in this case.

Figure 8: Bathometric survey of river channel at Mile 50.9 Landslide



2.5 Utility of Risk Scenario Approach at Ashcroft Mile 50.9

Understanding the entire RE:ESI risk scenario at the Mile 50.9 Landslide has enhanced CN's hazard and risk management of the site and others in the following ways:

- A full understanding of the interrelationship between river erosion and earth slides has provided a better understanding of the risk exposure and aided in the realization of the most effective risk control measures.
- Focused attention on the river morphology and the importance of scour protection as a practical means of early intervention.
- Broadened the scope of the investigation and monitoring to include heightened monitoring in the Fall, more extensive and directed installation of piezometers and borehole inclinometers, development and implementation of electric beam level sensors to monitor minor deflections of the track and utilize InSAR (Stewart et al, 2003) technology to detect and measure small ground movements in the 13 kilometre reach occupied by similar landslides.
- Understanding the evolution process of these landslides has provided search criteria used to identify and assess risk levels of other similar landslides in this reach of the Thompson River.

3 SKEENA MILE 28.0 LANDSLIDE

3.1 Setting

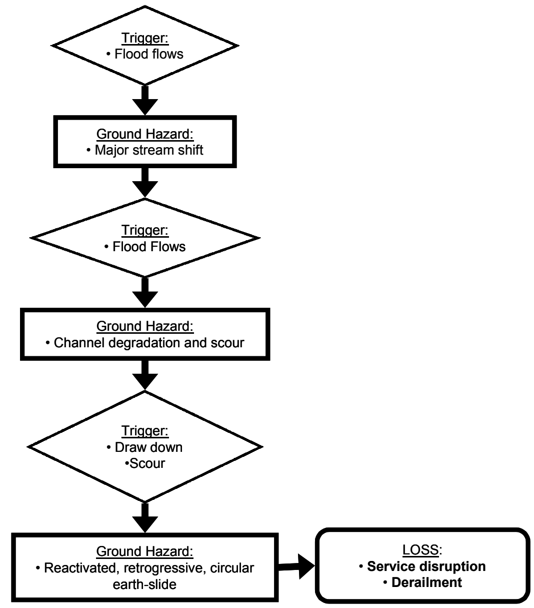
The second case example selected to illustrate the utility of identifying the RE:ESI risk scenario is located at Mile 28 of CNR's Skeena Subdivision (45 km west of Terrace, BC) which carries freight and passenger service between Terrace and Prince Rupert. The air photograph in Figure 10 locates the site in the context of the river. Most of the subdivision follows the right bank of the Skeena River and parallels Highway 16. At Mile 28, CNR tracks and Highway 16 are right beside each other occupying the same embankment with CNR on the riverbank. A bedrock knoll bounds the highway on the upslope side.

This RE:ESI risk scenario involves rapid river erosion of cohesionless bank soils, leading to rapid, retrogressive earth-slides of the riverbank. Where the railway occupies the bank, loss of track can result. Two such landslide events occurred on February and July 2002 at Mile 28 of the Skeena Subdivision, with the latter event undermining the railway grade.

3.2 Summary of Skeena Mile 28 RE:ESI Risk Scenario

The RE:ESI risk scenario at Mile 50.9 Ashcroft is summarized in Fig. 9. The initial ground hazard in the scenario is the major stream shifts that occur in the anabranching Skeena River which are triggered by flood flows in the river. These flood flows occur either from spring snow melt or heavy rains in the water shed. The second hazard in the scenario is classed as a combination of channel degradation and meander scour

Figure 9: Flow chart depicting the Skeena Mile 28 Landslide Risk Scenario



as the new channel evolves to its mature state. This hazard event is also triggered by flood flows. The final hazard in the scenario, which inevitably results in loss to the railway, is classed as a reactivated, retrogressive earth-slide. This can be triggered by either removal of material at the toe or by draw down conditions. This event can and has resulted in track failure that may lead to a significant service disruption or derailment. Following is a description of each of the components of this risk scenario starting with the earth-slide hazards.

3.3 Skeena Mile 28 Earth-slide

On February 20th, 2002, a small earth-slide occurred over a period of a few hours on the riverbank between Miles 28.04 and 28.06 of the Skeena Subdivision. As seen in Fig. 10, the landslide occurred on the north or right bank of the Skeena River above an outward bend in the main channel. The main scarp was located within 1.5m of the track centreline. Although the track showed little noticeable deflection an 80 m arc shaped tension crack had formed in the highway pavement reaching the centre line of the highway at the midpoint. In less than 24 hours, the slide scar was backfilled with angular riprap and the track re-opened.

Concerns about the site prompted site investigations to begin immediately. These included drilling with borehole inclinometer and piezometer installation, laboratory soil characterization, and bathymetric and ground surveys. Following are the main findings from the investigation and analyses:

- The bathymetric survey indicated the river thalweg was against the north bank, and scour had undermined riprap protection on the bank steepening the lower bank slope. It also indicated the slide debris had partially infilled the thalweg at the toe of the earth-slide but scour holes still existed upstream and downstream of the slide;

Figure 10: Skeena Mile 28 location photograph

- Scour events during past floods are recognized as the key preparatory factor to the earth-slide hazard. The February failure classed as a rapid rotational earth-slide was likely triggered by a rise in soil pore pressures from snowmelt or draw down conditions brought on by a period of low river level following formation of a scour hole.
- Fig. 11 presents one interpretation of the stratigraphy at the site. The basal rupture surface was likely bounded in a loose sand horizon.
- Analysis indicated that a deeper potential rupture surface was marginally stable in a low sensitivity, soft, low plasticity, glacio-marine clay and silt that underlay the granular and loose sand horizons. The Liquid Limit of the silts ranged between 22.8% and 24.9% while the Liquid Limit of the clays ranged between 33.3 and 35.0%.

Fig. 12 shows the riverbank immediately following the site investigations and the February bank repair.

Prior to spring runoff, CNR undertook additional riprap work upstream and downstream of the February slide site. Despite the additional riprap protection, a second failure occurred at or near the same location during spring snowmelt runoff on July 18th, 2002. This time the earth-

Figure 11: Interpreted stratigraphic cross-section looking downstream. (Note: 2:1 vertical exaggeration)

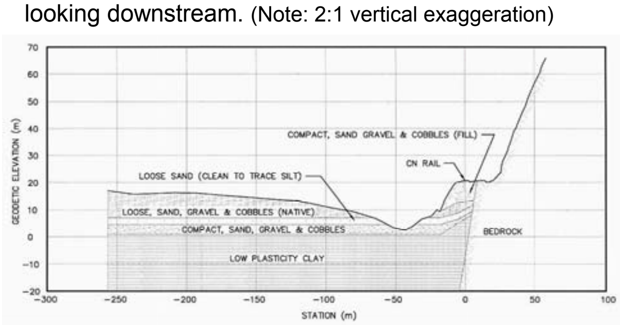


Figure 12: View looking downstream after site investigations and February bank repair.
(The slope inclinometer casing in the photograph is near the upstream edge of the backscarp).

slide had retrogressed to involve the track grade and the left lane of the highway but had stopped at the ledge in the bedrock surface encountered near the centreline of Highway 16. As shown in Fig.14, both earth-slide events occurred in the eastern half of the scour hole coincident with the bedrock knoll on the north side of Highway 16.

Figure 13: Skeena Mile 28: View looking downstream at July 18 landslide site

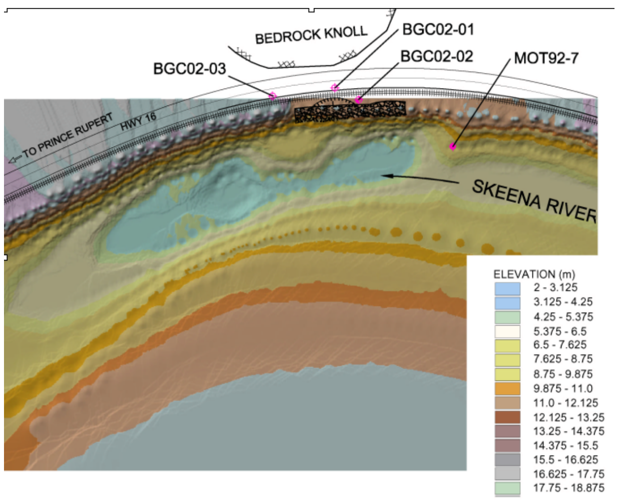
The failure removed support for the rail grade and produced tension cracks in the adjacent Highway 16. Fig. 13 illustrates the site following the earth-slide event. The location of the failure can be related to Fig. 12 using the slope inclinometer casing visible in both photographs. Immediate repair was made by filling the slide scar with riprap and temporarily re-aligning the rail grade to occupy one lane of the highway.

A second bathymetric survey after the July failure indicated that the scour holes downstream of the February failure had deepened since the March, 2002 survey. Figure 14 shows shaded bathymetric contours from this second survey that illustrate the scoured area and the partial infilling of the scoured area by material from the July failure.

A more extensive riprap program was undertaken to further reinforce the earlier riprap construction. It was recognized that continued erosion and undermining of riprap would likely occur. Since it was impractical to place riprap to the bottom of the thalweg using equipment on the bank, the scour hazard was mitigated by construction of a riprap launching apron of sufficient size to retard future undermining from scour at the toe. In total, approximately 20,000 m^3 of riprap was placed. In addition, a real-time warning system of mercury switches on tip-over posts linked to the railway signal controls were installed on the riverbank through the affected area.

It is inferred that the second failure was triggered by additional river scour during high flow. The July 18th landslide is classed as a rapid reactivated retrogressive rotational earth-slide.

Figure 14: Skeena Mile 28 -Slope shade image of July 2002 bathymetry.



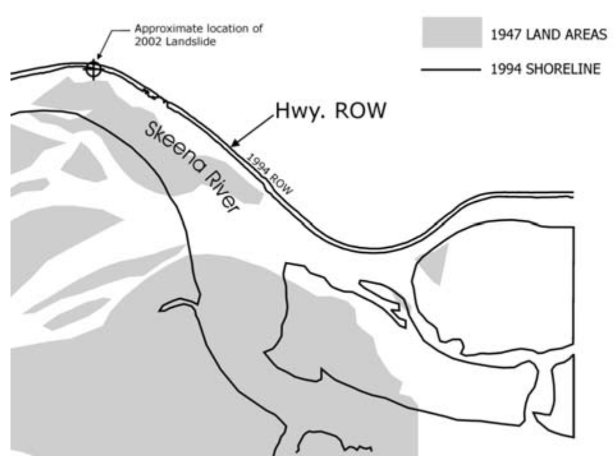
3.4 Skeena Mile 28 River Erosion Hazards

The Skeena River in proximity to Mile 28 is an anabranching river. The channel width is generally 500 m occupying a steep sided valley with a width of approximately 2 km. Major islands in the river are generally wider than 1.5 km. The channel gradient is measured at 0.00057m/m. Anecdotal accounts indicate that extreme floods reach a level approximately 0.3 m above the track at Mile 28 approximately 12m above the thalweg. The bed consists generally of gravel and cobbles. The natural channel banks are generally covered with cobbles and boulders, but have been modified considerably on the right bank by railway and highway construction and maintenance.

Anabranching implies the river is laterally unstable; channels may be abandoned or reactivated during significant floods. Vertically, the river is generally stable unless recent channel shifts have occurred. This is because sudden flow path changes can lead to dramatic changes in channel gradient, which in turn can lead to bed degradation or aggradation. To investigate this further the temporal changes in the river morphology at the Skeena Mile 28 site were examined.

A series of air photographs from 1937 to 1998 were examined to map changes in the river flow patterns and bank position. In 1937, the majority of flow in the Skeena was located on the south side of the valley and did not impact on the track. By 1963, the main channel had migrated north until it was against the north bank, although the river curvature was less than is presently the case. Between 1963 and present, the outer edge of the meander migrated downstream and the angle between the main direction of flow and the north bank appears to have steepened such that the flow is now directed more toward the riverbank as opposed to along it. Figure 15 shows an overlay of the 1947 channel location on the 1994 location, illustrating the major shift of the main river channel.

Figure 15: Skeena Mile 28 - Overlay of 1947 and 1994 river locations.



Traces of the river channels from the 1947 and 1994 photographs were overlaid to quantify the bank erosion. This work illustrated that the north bank near Mile 28 has been eroding since 1963 at a rate between approximately 0.3 m/yr in the upstream half of the river bend, to 0.75 m/yr at the downstream limit of the bend.

From the above, it seems appropriate to split the hydrotechnical component of the risk scenario into two basic hazards as follows:

1. Major stream shift hazard - triggered by flood flows and
2. Channel degradation and scour hazard (Savigny et al, 2002) - mainly triggered by flood flows.

It should be noted that because of the relative youth of a new channel formed after the major stream shift, degradation and scour processes are working year round but are accelerated during flood events. Consequently, the February 2002 failure at Mile 28, which occurred at low water level, may have partially been triggered by this year round scour process removing the erodible toe material.

3.5 Utility of Risk Scenario Approach at Skeena Mile 28

Understanding the entire RE:ESI risk scenario at the Skeena Mile 28 Landslide has enhanced CN's hazard and risk management of the site and others in the following ways:

- It has provided a fuller understanding of the scope of the risk exposure to CN from the interrelationship between an instable river environment and earth slides and thus focused attention on only the key components such as major stream shifts in the Skeena River and where local degradation and scour is impacting the track grade.
- The fully defined risk scenario has provided a more focused approach including a regional historical study and bathymetric surveys to search out other potential earth-slide hazards resulting in timely intervention.
- It has helped to direct a more specific site investigation and monitoring program and aided in the realization of the need and extent of warning devices.

4 CONCLUSIONS

Describing the ground hazard risk exposure in the context of a risk scenario such as the RE:ESI provides a powerful predictive tool by mapping out the potential future chain of events in terms of mechanical, temporal and spatial attributes.

It provides a tool for searching out similar risk scenarios and hazards whereby intervention is focused at critical links in the chain thereby optimizing risk control efforts.

Breaking out the hazard of river erosion induced land sliding into its river erosion (RE) and earth-slide (ESI) components facilitate the independent evaluation of vulnerability to each hazard, and highlight the chain of events that predominantly result in loss. Combining the hazard vulnerabilities in a risk framework can then be used as a tool to quantify RE:ESI risk, and prioritize risk control efforts. The actual risk to the railway, in this case, is estimated by a determination of the frequency and severity of the entire risk scenario not just its components.

The paper illustrates the utility of applying the CSA Standard, Risk management: Guidelines for decision makers (CSA,1997) to the risk associated with railway ground hazards.

Finally, it has facilitated effective communication of the risk problem to a widened circle of stake owners.

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