Development of a Slope Risk Rating System for New Zealand Rail

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ABSTRACT

Due to the steep topography and the unstable nature of much of the New Zealand's geology coupled with relatively frequent rainstorms, hillslope instability events occur reasonably frequently around the New Zealand rail network. Until recently, KiwiRail has responded to slope risks on a reactive basis i.e. treatment of the effects of slope instability rather than the causes. This approach carries an ongoing associated risk to passenger safety and commercial railway operation.

In its role as a public transport provider, KiwiRail is increasing its awareness of the potential slope risks present around the rail network. The slope rating system outlined in this paper enables KiwiRail to undertake a systematic assessment of the slope risks to the rail network and will allow a proactive approach to the treatment of the identified risks.

The slope ranking system is points-based and considers parameters such as slope material condition, slope and height angle, vegetation cover and the history of failure. The sum of these conditions is then factored for line speed, stopping distance and the potential effects of train derailment.

This paper describes the historical context of slope instability affecting the New Zealand rail corridor and the former reactive practices used to mitigate slope instability risk. The paper then outlines in some detail the slope rating system that has been developed by KiwiRail. Lastly, the paper discusses how the outcomes of this assessment are incorporated into KiwiRail's strategic initiatives.

Keywords: slope risk rating, strategic risk management, rail network

1 INTRODUCTION

There are many areas along the New Zealand rail network which are located within geologically challenging terrain. A combination of steep slopes, geologically young and weak materials, poor historical construction practices and high rainfall has led to many instances of slope failures affecting the rail network (Figure 1). Until very recently, KiwiRail has dealt with slope instability risk almost entirely reactively. After a landslide event has occurred, debris is removed and management measures for the immediate area of the track are put in place. The management measures typically involve either: placing a speed restriction, placing the site on a list for routine inspection, or constructing some form of (typically non-engineered) slope retention.

One of KiwiRail's objectives over the next 10 years is to improve route reliability through a rigorous management of risks. A key part of this improvement will be effectively managing the geotechnical risks (landslides, rock falls and embankment collapse) that exist along the rail network. Without effective management, these geotechnical risks continue to pose unacceptably high levels of risk to the rail network.

In order to achieve a safer and more reliable rail network for commuters and for freight, the risks need to be identified, understood and managed. The slope hazard rating system recently developed by KiwiRail enables the slope hazards to be systematically assessed along all of the approximately 4,000km of the New Zealand rail.

Figure 1: Recent landslides along the NZ rail corridor. Left: Palmerston Nth – Gisbourne Line (PNGL) near Woodville, North Island (Sept 2010). Right: Main North Line (MNL) south of Kaikoura, South Island (Sept 2010).

2 SLOPE RANKING SYSTEM

The slope ranking system provides KiwiRail with the ability to identify and systematically treat slopes using a transparent and defensible process. The system is not intended as a method of predicting which slopes will be the next to fail, as this will depend substantially on localised rainstorms or earthquake events. It draws on some existing publications, including Network Rail (2008) and Hoek (2007) but has been developed substantially in-house, which is a reflection of New Zealand's relatively unique combination of occasionally difficult engineering geology, topography and rainfall.

The slope ranking system is points-based. Points are assigned on the basis of a number of factors including material condition, inferred ground water level and line of sight. Slopes with high ratings have in general terms a higher level of risk compared to those slopes with low ratings.

2.1 Rating Assessment

The slope rating determined for any one site is calculated as follows:

Rating = (Sum of points contributing to likelihood of failure occurring) x (consequence factors if failure occurs)

Factors contributing to likelihood of failure comprise the following rating categories:

1. **Slope Stability**:
    a. Whether the site would be subject to a fall onto the track ('cutting failure') or subsidence below the track ('embankment failure'; refer Figure 2);
    b. Site geometry (slope height and angle)
    c. Material type and water condition
2. **Vegetation Cover** – typically vegetation will have a beneficial effect for soil slopes; but may have an adverse effect for rock slopes
3. **Adjacent Geometry** – this is a measure of the slope above the cutting or below the embankment. Cuttings with steep 'fall-in' slopes are considered more likely to fail compared to those slopes which fall away behind the cutting
4. **Adjacent Hydrology** - Areas where concentrated water flow can occur or areas with inadequate drainage measures in place would be more susceptible to landsliding
5. **Failure History** – This is based on site observation as well as experiences of key personnel and information obtained by KiwiRail's incident reporting system
6. **Future Instability Rating** - This is a subjective assessment of the potential for instability to occur in the future and is based on site observation (eg bulging at the toe of the slope; incipient cracking along the crest of an embankment)

Factors contributing to the consequence, should failure occur, comprise the following categories:

1. **Site Distance Factor**: This is a measure of the ratio between available line of sight and stopping distance (i.e. an assessment of whether a train driver could stop prior to impacting debris)
2. **Runout distance factor** (cuttings) or **Crest loss distance factor** (embankments): This is an effect of the distance between the rail track and the area of instability. For a given slope height, the greater this distance is, the less potential for a failure to affect the track.
3. **Derailment Effect**: This is a subjective measure of the likely effect should derailment occur at the subject site. For example, derailment in a box cutting may mean the train is supported by the opposite cutting. In contrast, derailment over a high embankment means there is a considerable likelihood of downslope travel, which may have much more serious consequences
4. **Traffic Volumes:** are considered for metro areas only. Traffic volume is not considered for 'freight' segments of the network. In these areas, line segment importance and the resulting prioritisation of works is dealt with strategically, rather than as a component of the rating system

The maximum possible slope rating that can be calculated is 506 (outside of metro areas). The minimum is zero. The flow diagram on the following page (Figure 2) provides a summary of the calculation process for the rating system.

2.2 Assessment Process

Field assessments and rating calculations are conducted by competent geotechnical professionals using an 'App' running on an Android Tablet platform which has been developed specifically for the purpose. The requirement for the use of professional personnel is to ensure that the rating is never simply undertaken as a 'black box' approach. KiwiRail considers that it is imperative that the rating developed for each site is critiqued against other sites to ensure that the level of rating assigned is commensurate with other sites of similar risk.

For safety purposes the assessment is undertaken in two-person teams, supported by hirail vehicles where access is difficult. In the assessment process, the whole of a particular route is required to be systematically assessed. Areas where a slope or embankment has not been noted are therefore not considered to have any significant risks of slope instability.

3 PHILOSOPHY AND TECHNICAL DERIVATION

Development of the Slope Rating System has been an iterative process and has relied extensively on engineering judgement and interpretation, taking into account the relative priority of factors as outlined below.

- For soil materials and rock masses where mass failure is considered to be the mechanism of failure, the slope stability rating is determined on a linear scale between 0 and 100 based on limit equilibrium modelling using assumed average parameters for the soil or rock type.
- Defect controlled rock slopes are similarly assigned points between 0 and 100 for their slope stability rating, based on defect persistence and orientation relative to the cut face, in combination with typical precipitation and the likelihood of freeze-thaw action.

Secondary effects (vegetation cover, fall-in angle, slope hydrology and failure potential) have been assigned lower point values as their influence on slope stability is considered to be less compared to the slope stability rating. For each of these secondary effects, the assigned point values have been determined reasonably subjectively; essentially using a trial and error approach. Further discussion on the rating scores is provided in Section 3 and shown graphically in Figure 2.

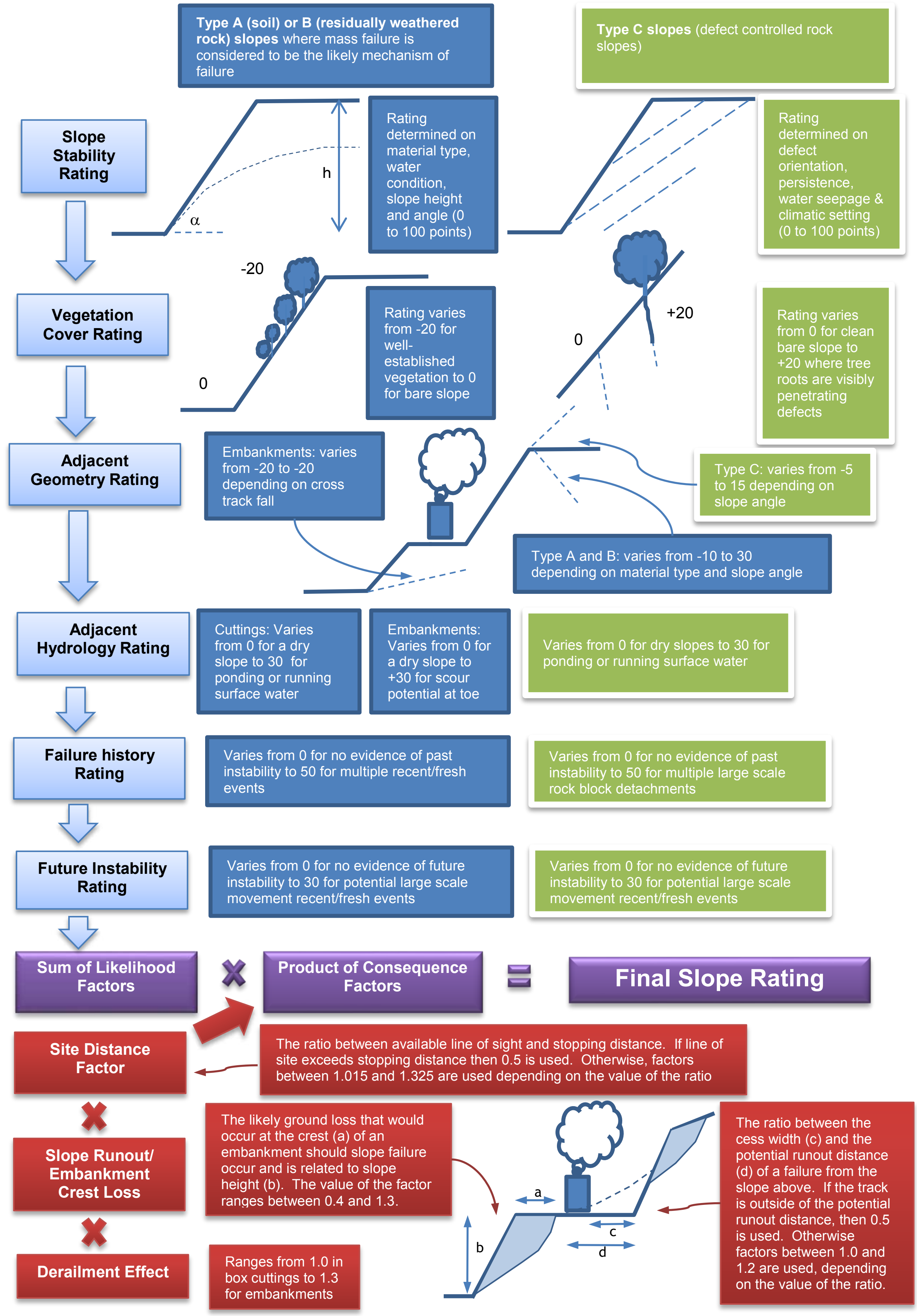


Figure 2: Summary of Slope Rating Process (Freight areas of the network)

3.1 Likelihood Factors

Details of the slope rating system cannot be fully outlined in this paper given limitations on length. However, by way of a worked example, Tables 1 to 6 outline the likelihood ratings that would apply to a cohesive soil cutting. Consequence factors are provided in Section 3.2.

Slope Height	Slope Angle (°)	Dry Slope (Condition 1)	Low Groundwater Slope (Condition 2)	High Groundwater Slope (Condition 3)
		Points	Points	Points
<3m	60	90	90	100
	50	70	90	90
	40	50	70	90
	30	30	50	70
	20	10	30	50
3-6m	60	100	100	100
	50	90	100	100
	40	70	90	100
	30	50	70	90
	20	10	50	70
6-12m	60	100	100	100
	50	100	100	100
	40	90	100	100
	30	70	90	100
	20	30	70	100
12-25m	60	100	100	100
	50	100	100	100
	40	100	100	100
	30	70	100	100
	20	30	90	100
>25m	60	100	100	100
	50	100	100	100
	40	100	100	100
	30	90	100	100
	20	30	90	100

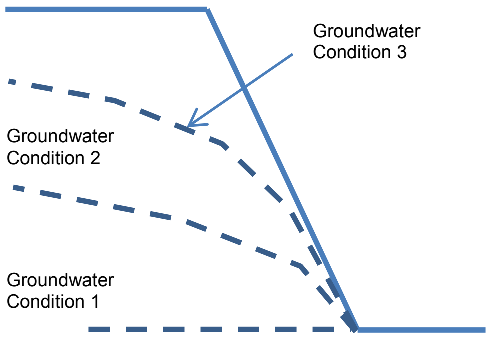


Table 1. Material Strength Ratings for Soft to Firm Cohesive Soils Relative to Assumed Groundwater Level

Predominant Cover Type	Points
Well-established, dense, mature & deep-rooted veg.	-20
Patchy deep-rooted or well-established shallow rooted	-10
Patchy shallow-rooted veg with bare areas	-5
Bare slope	0

Table 2. Rating correction for Vegetation Cover (Soil Slopes)

Adjacent Ground	Points
Falls away	-10
Level - 10 deg. Fall In	10
10 - 30 deg. Fall In	20
> 30 deg. Fall In	30

Table 3. Rating correction for Slope Fall in Angle (Soil Slopes)

Cuttings	Points
Dry	0
Crest / Slope Concentration Features(s)	10
Hydrophilic Veg. / Marshy Ground	20
Ponding or Running Surface Water	30

Table 4. Rating correction for Slope Hydrology

Description	Points
None	0
Isolated Historical / Overgrown	10
Several Historical / Overgrown	20
Single Recent / Fresh	30
Multiple Recent / Fresh	50

Table 5. Rating correction for Failure History

Description	Points
None	0
Evidence of Minor/Small Scale Instability	10
Evidence of Major/Large scale	30

Table 6 Ratings for Indications of Future Instability

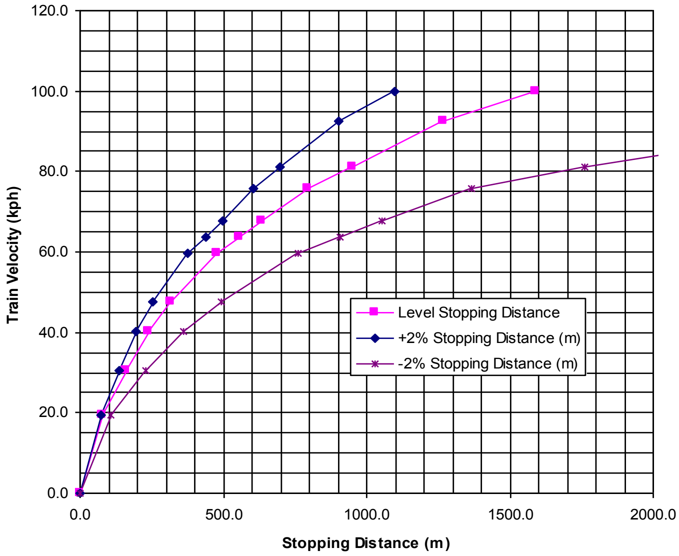
For example, a relatively dry, well vegetated 5m high cut in a firm clay at an angle of 40°, with a fall-in angle above the cutting of 20°, one isolated historical failure and no evidence of future instability would score 80 points.

3.2 Consequence Factors

The consequences of failure are considered as multipliers to the Likelihood Rating as outlined in the following sections. Similarly to the measure of likelihood, values for each consequence factor have been determined largely on a trial and error basis to balance the effect that any category has on the final rating calculated. Again, due to space limitations, information for cuttings only has been given.

3.2.1 Site Distance

Figure 3 below outlines the factors that have been calculated for Site Distance.



Site Distance (% of stopping distance)	Factor
>100%	0.5
75 – 100%	1.015
50 – 75%	1.055
50 – 30%	1.11
30 – 15%	1.175
15 – 5%	1.25
<5%	1.325

Figure 3: Consequence Factor for Stopping Distance. The graph on the left shows typically stopping distances for NZ freight trains relative to speed and grade

3.2.2 Runout Distance

Runout Distance (or crest loss distance for embankments) is a measure of the possibility of track blockage shout slope failure occur as shown in Table 7 below.

Category	Description	Cess width as a % of runout distance	Factor
A	Track is located well inside potential landslide runout distance. Derailment likely or certain to occur should slope fail	Less than 50%	1.2
B	Track is located inside the potential runout distance. Impact with train likely. Derailment is a possibility, but not a certainty	50% to 80%	1.08
C	Track is located near the edge of the landslide runout distance. Impact with train a possibility, but derailment unlikely to occur	80% to 99%	1.0
D	Track is outside of the potential landslide runout distance. Impact with train unlikely. Derailment cannot occur, irrespective of the likelihood	100% or greater	0.5

Table 7 Runout Distance Categories for Cuttings

3.2.3 Derailment Effect

Derailment effect values are provided in Table 8 below.

Description	Factor
Low probability of overturning (Box Cuts)	1.0
Some probability of overturning (Level ground)	1.1
Potential for downslope travel (embankments or sidling slopes	1.3

Table 8 Factors for Derailment Effect

Continuing the example cutting outlined in Section 3.1, if it was assumed that the site distance ratio was calculated at 8% (ie relatively poor line of site), and the track was located very close to the toe of the slope (as is often the case) and is within a box cut, then the final rating would be (80 x 1.25 x 1.2 x 1.0 = 120).

4 STRATEGIC RISK MANAGEMENT

At the conclusion of each field study, the slopes are ranked to assess the distribution of ratings for the particular line and assess appropriate risk treatment options for the subject section of track. Risk treatment measures will typically involve one of the following:

1. Engineering works to actively reduce the level of risk. These range from comprehensive works (retaining walls, anchored rockfall netting or sprayed concrete) to more modest measures such as toe fences to prevent material accumulating in cess drains
2. Slope monitoring to provide an early warning of debris/rock fall onto the track, or embankment subsidence. Monitoring decreases the risk of a train derailing, but does not decrease the likelihood of the instability occurring nor decreases the financial risk associated with track outage
3. Accepting the level of risk with periodic review of the slope conditions to assess the level of deterioration (if any) of the slope with time
4. Accepting the current level of risk without the need to future review

Which of these options is the most appropriate is a function of the determined slope rating as well as strategic initiatives which will likely change over time.

Recently, KiwiRail has embarked on a 10 year program termed the 'Turn Around Plan' (TAP) which is aimed to create a sustainable business for rail in New Zealand. Freight accounts for 75% of revenue for KiwiRail. Typically, heavy freight sections run few if any passenger services. Because the slope system deliberately does not take into account line importance for freight sections, the decision to what value risk reduction works are undertaken on a particular line can be made based on a combination of strategic initiatives under the TAP (for example a focus on the North Island Main Trunk (NIMT) between Auckland and Wellington and the Main North Line (MNL) between Picton and Christchurch). Risk reduction works in the metro areas in Auckland and Wellington are based on the highest rated sites when traffic volumes are considered.

5 CONCLUSIONS

The slope ranking system that has been recently developed by KiwiRail provides the following key benefits:

- Improved knowledge of the risks associated with the various slope sites along the rail network;
- Identification of current 'at risk' sites;
- Enabling proactive (rather than reactive) management of the slope instability risk posed to the rail network;
- Ranking of slope assets, leading to a more accurate projection of future expenditure and programming;
- Proactive approach to identifying potential problems, allowing timely and cost-effective solutions to be designed and implemented;
- Providing KiwiRail with a process to implement targeted risk reduction works, reducing over time the potential for track outages and possible train derailments;
- Providing KiwiRail with a transparent and justifiable basis for selecting sites for remedial works.

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