Published Project Report
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Rock slope risk assessment

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Transport Research Laboratory

PUBLISHED PROJECT REPORT PPR554

Rock slope risk assessment

by P McMillan and I M Nettleton

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Contents

Foreword

This report is one of three that form a series dealing with key issues related to rock engineering, as follows:

- Rock slope risk assessment.
- Rock engineering guides to good practice: road rock slope excavation.
- Rock engineering guides to good practice: rock slope remedial and maintenance works.

The reports were completed between 1995 and 2000 and although they were circulated to interested parties during the intervening years they were never formally published. The work that informed the reports was undertaken for the predecessor organisation of Transport Scotland over a period of around 20 years. At the request of the Highways Agency, and with the permission of Transport Scotland, these reports are now being published for the first time.

The available time and resources mean that updating and supplementing is not a viable option and the work undertaken to achieve this has been restricted to updating the format to suit the TRL Published Project Report Series and generally tidying up the unpublished versions. The sole major exception to this is the report on Rock slope risk assessment to which an appendix has been added on ravelling. This is intended to open up the system reported and to render it more usable for rock slopes in southern England as well as those in Scotland for which it was originally intended. This appendix was prepared by Ian Nettleton (Coffey Geotechnics), who was closely involved in the application of the system while in the employ of TRL. The authorship of this report has been amended accordingly.

I sincerely hope that these reports will be subject to wide industry uptake as have so many TRL Reports before them.

Dr Mike Winter
Head of Ground Engineering
March 2011

Executive summary

Effective management of potentially hazardous rock slopes requires knowledge of the location of these slopes and of the level of hazard posed to the road user. It is then possible to prioritise further action. However, present rock slope stability and hazard assessment systems employ variable approaches to data collection and presentation of results, making comparison of results almost impossible. In addition, these assessments are usually undertaken on a reactive basis, prompted by rock falls. Problems are therefore, not addressed until after road users have been exposed to the hazard, considerable budgetary problems arise as incidents are unforeseen and prioritisation of funds is impossible.

Improved methods of identifying and classifying rock slope hazards are therefore required to overcome these problems and allow effective management of rock slopes on the Scottish Trunk Road Network. To this end a programme of research was instigated by SOID, National Roads Directorate in 1993. The first stage of this research, Rock Slope Risk Assessment, is now complete and has resulted in the development of a new two stage approach to the assessment of rock slope hazard.

The first stage of the new approach derives a Rock Slope Hazard Index from rapid, standardised field data collection. The results are used to classify rock slopes into four action categories. The second stage of the new approach derives a Rock Slope Hazard Rating from semi-probabilistic analysis of data recovered from a detailed field survey. The Rock Slope Hazard Index is intended to act as a coarse sift, identifying potentially hazardous slopes. The Hazard Rating is intended to act as a fine sift, identifying the level of hazard at each rock slope and allowing prioritisation of maintenance.

A trial of the Rock Slope Hazard Index was carried out on the A830 between Fort William and Mallaig. This demonstrated that the Index can be used as a maintenance management tool. However it also demonstrated that more detailed guidance on data collection procedures is required to obtain consistent results from Hazard Index surveys.

Management of rock slope hazards on the Scottish Trunk Road Network could be significantly improved through application of this new approach to hazard assessment. However the following actions should be undertaken before implementation:-

1. Detailed trials of the Rock Slope Hazard Rating are required.
2. The Rock Slope Hazard Index should continue to be used under close supervision.
3. Further research is required to improve understanding of the influence of some parameters on rock slope hazard.
4. Further work is required to improve and automate data analysis for the Index and Rating.
5. Detailed user guidance manuals should be compiled for both the Index and Rating systems.

Abstract

The management of rock slopes requires knowledge of their location, traffic levels and other geometric parameters as well as the level of the hazard posed to the road user. This information can then be used to prioritise remedial action. This report details a system that was developed to allow such assessment and prioritisation on the Scottish road network.

1 Introduction

The uncontrolled use of bulk blasting techniques and application of "standard" designs have left a legacy of many unstable highway rock slopes in Scotland. Some unstable slopes are a hazard to the road and road user and remedial action is therefore required. Effective management of these requires a knowledge of the location of all unstable rock slopes and an indication of the level of hazard posed to the road user. It is then possible to prioritise future action.

At present rock slope stability assessment and hazard evaluation are usually undertaken on a reactive basis often prompted by rock falls. Such a reactive approach does not address problems until after road users have been exposed to the hazard and presents considerable budgetary problems as incidents are inevitably unforeseen. A proactive approach to rock slope stability hazard aims to remove the hazard to road users prior to incidents occurring and to allow effective priority based budgeting of maintenance funds. A standard, repeatable and rapid method of rock slope hazard assessment is required for such a pro active approach. At present there are several subjective~ hazard assessment schemes in use by different specialist consultants. All of these schemes have their limitations and none meet the criteria for an effective proactive system.

A research project was commissioned by SOID/CSU in 1993 to investigate rock slope risk assessment and if necessary develop new methods of assessing rock slope risk. This project report presents the findings of that research.

2 Background to Risk Assessment

Risk assessment is a complex subject area which has been the subject of considerable recent investigation (Chowdhury 1992, Hambly and Hambly 1994, Skipp 1993). There are many definitions of risk assessment some of which are simple others of which a complex. Chowdhury (1992) provided a good overview of risk assessment as applied to geomechanics and Table 1 is taken from that paper.

Risk assessment as defined by most authors is a quantitative assessment under clearly defined conditions. In theory it is possible to calculate the risk associated with different situations or activities (using a standard calculation procedure) and compare the results on a single scale to determine which is most serious. An example would be comparing the risk of an accident occurring on a stretch of road with poor visibility and little overtaking opportunity with the risk of an accident occurring at a busy junction. In this case it is possible to study historical precedent for both situations and develop models which can derive a measure of the probability of accidents for the two situations. These probabilities can then be developed into risk levels and compared. The situation with the highest risk could then be regarded as the highest priority for improvement.

It is difficult to apply this type of quantitative, probability based risk assessment to highway rock slopes as many elements of rock slope instability are difficult to quantify. In particular prediction of likely failure timing and frequency are difficult and unreliable. In Scotland this is in part due to poor historical data on rock slope failures. Therefore, any assessment of risk associated with rock slopes will, to some extent, be dependant on an assessment of rock slope stability. The results of such assessments are not totally compatible with those from quantitative risk assessments.

Table 1

Definition
Simple definitions
1. Risk = Probability of failure
2. Risk = Probability of failure multiplied by the loss from failure = Expected loss, expected damage or expected cost
3. Risk = PC + f (P,C,x) Where:- P = Probability, C = Consequence and f is some function of P,C and other relevant variables x (x could be a measure of fairness of risk, its nearness today, how catastrophic it is)*
Symbolic definitions
1. Risk = Uncertainty + Damage
2. Risk ÷ (Hazard / Safeguards)
3. Risk consequence / unit time = frequency events / unit time x magnitude consequence / event
4. Risk = [(Event / unit time) (Consequences / event)]
5. Risk = [(Events / unit time) (Consequences / events)^k] Where k > 1 is used to amplify the importance of events with large damages
* Note: A person or society which acts on the basis of :- f = 0 is called risk neutral f > 0 is called risk averse f < 0 is called risk prone.

At present no satisfactory methods of assessing risk associated with rock slope instability that could be applied to a highways setting are known to the Author. The current research has attempted to distil current knowledge, inject new thinking based on expertise at TRL Scotland and develop a new approach to risk assessment for rock slope instability. To avoid confusion with quantitative risk assessment the assessment systems developed as part of this research have been termed Hazard assessments. The definition of Hazard as used in this research could be loosely written as:

Hazard = Probability of Failure x Consequences of Failure

3 Factors Influencing Rock Slope Hazard

The hazard presented by a particular rock slope is dependent on a number of factors which fall into four broad groups as follows:-

3.1 Geotechnical Factors

These are factors associated with rock mass and material properties. Discontinuities present in rock masses have a major influence on slope stability. The important discontinuity properties are as follows (Figure 1):

a. Orientation (Dip and Azimuth (Dip Direction)

b. Spacing (Principal Spacing)

c. Trace Length

d. Dilation

e. Infill

f. Surface weathering

g. Roughness

h. Planarity

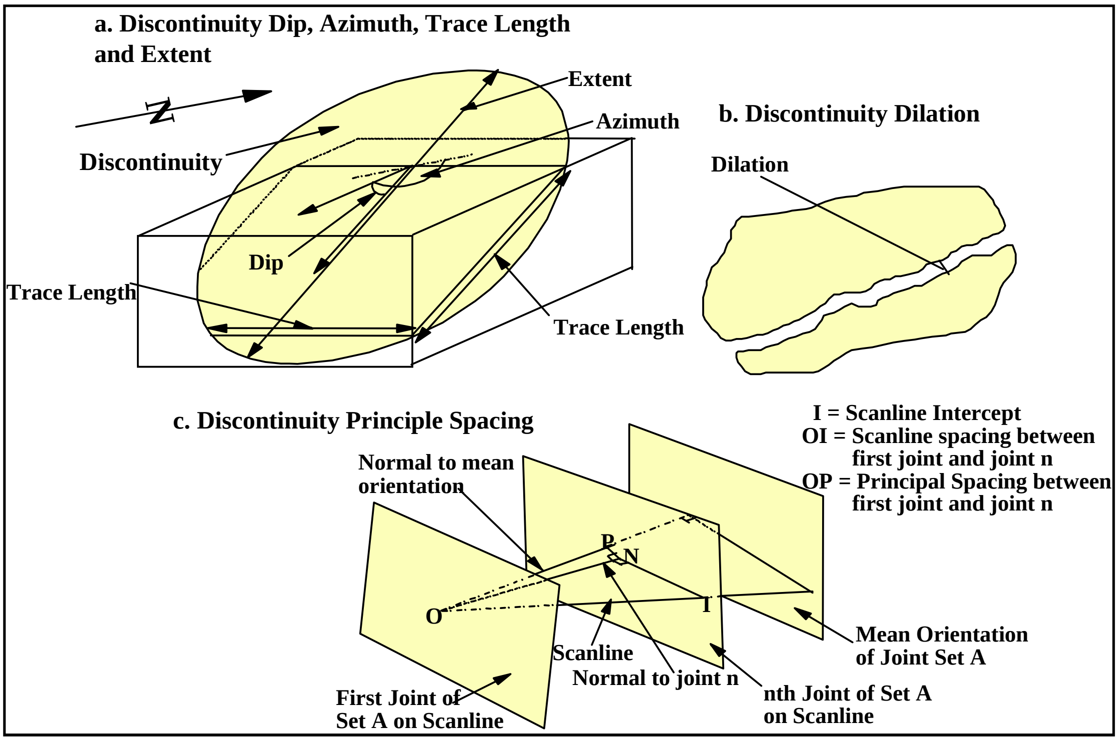

Figure 1. Illustration of Discontinuity Properties

These properties contribute to determining the type, size and likelihood of potential instability on a rock slope and are relatively easy to establish from a rock slope exposure.

Rock material properties also contribute to rock slope instability. The important material properties are:

a. Strength

b. Weathering

c. Mineralogy

These properties contribute to the possibility of failure and potential for development of future failures.

Finally water conditions on the slope also influence stability. Groundwater is of considerable importance and causes water pressures in discontinuities which often acting as the trigger to rock failures. Surface flows can also cause stability problems through washout, erosion and accelerated weathering.

3.2 Geometric Factors

Geometric factors are those associated with the geometry of rock cuttings, verges and roads. Important rock slope geometric factors are as follows (Figure 2):

a. Slope Height
b. Slope Angle
c. Slope Profile
d. Position and Size of Berms
e. Angle of Natural Slope Above Cutting

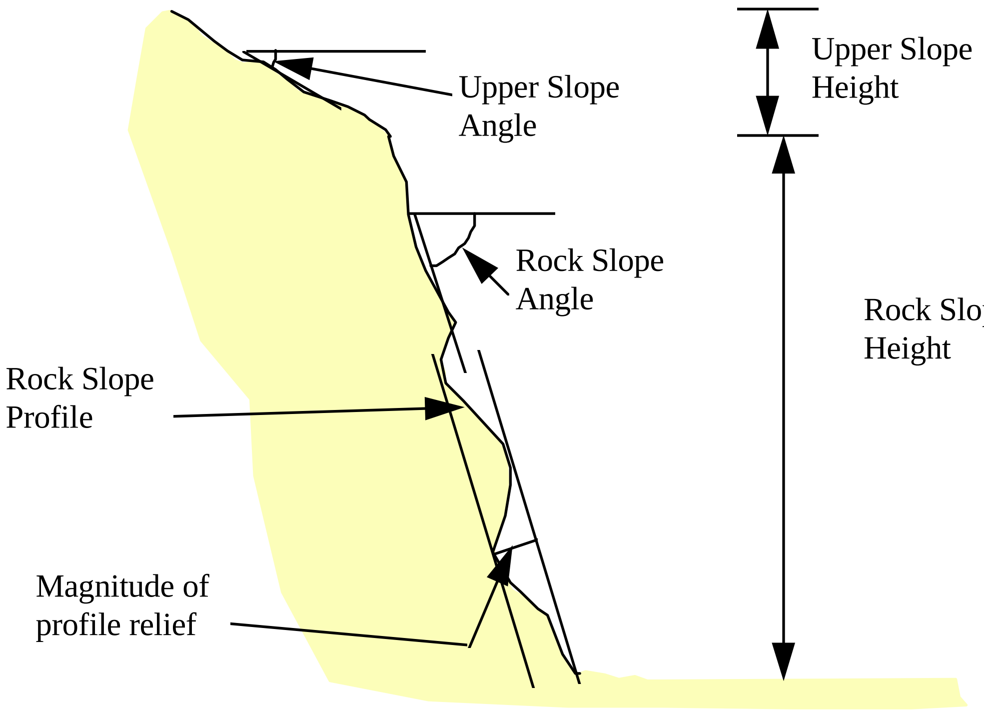

Figure 2. Geometric factors associated with rock slope geometry

Slope angle has an influence on the potential for failures on a slope. Slope height can influence slope stability and the hazard posed by instability. As slope height increases the scope for unfavourable discontinuities to daylight on the slope increases. Also the higher the slope the greater the height from which a failure can fall Slope profile and the position and size of berms influence block trajectory thereby influencing the hazard presented by failure. All of these factors can be measured or estimated in the field.

The geometric factors associated with the road verge are concerned with determining the potential for the verge to act as a rock trap and reduce the hazard presented by a rock failure. The larger the trap the lower the hazard. The important factors in that respect are as follows (Figure 3):

a. Verge Width
b. Ditch Width
c. Ditch Depth
d. Fence Height
e. Distance to fence from toe of slope
f. Verge Materials

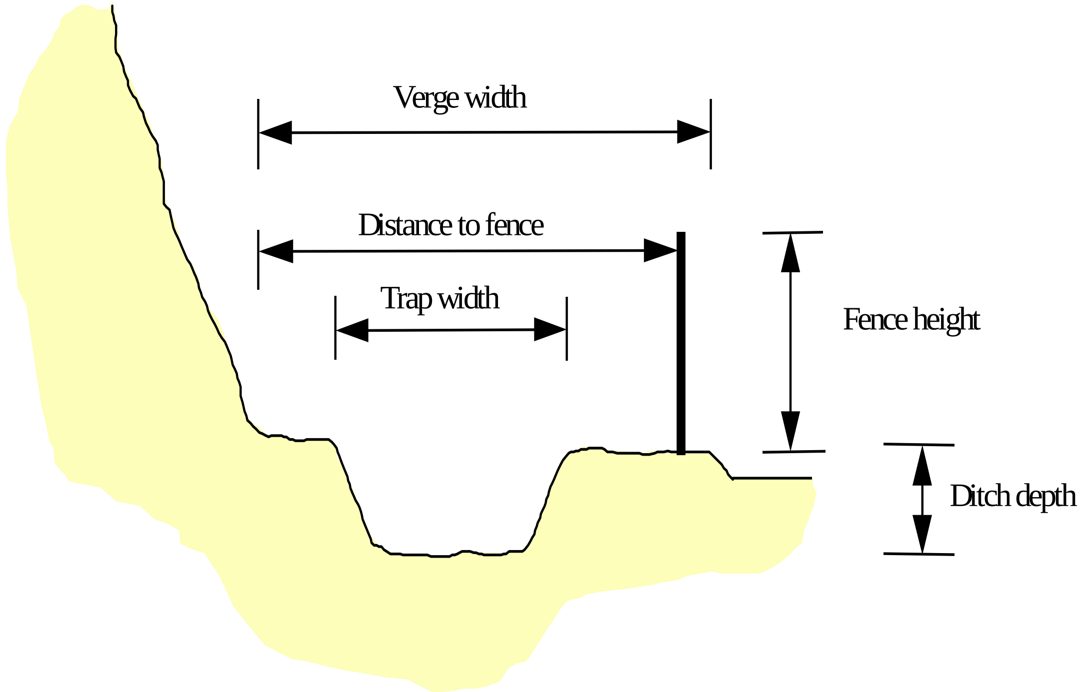

Figure 3. Geometric factors associated with rock slope verges

The geometry of a road can have a significant bearing on the hazard posed by rock fall. The important road geometry factors are as follows:

a. Carriageway width

b. Sight Lines at rock cutting

c. Type of Carriageway (Single track, single, dual)

A rock falling onto a narrow carriageway is more of a hazard than one falling onto a wide carriageway as there is more scope for avoidance on the latter. Sight lines influence the possibility of a vehicle stopping before impacting a rock fall on the road. The type of carriageway is important when considering traffic data (see Section 3.4).

Other topographic factors that influence the hazard posed by a rock slope are as follows:

a. Type of Cutting (box or side long)

b. Steep drop opposite cutting

c. Proximity of open water

d. Proximity of buildings

e. Proximity of services

All of these factors can effect the likely outcome of a rock fall incident. If a vehicle swerved to avoid a rock fall it could result in a serious incident if any of the above applied to the site.

3.3 Remedial Work Factors

Many rock slopes in Scotland have been subject to some form of remedial action in an attempt to reduce the hazard presented by rock fall. It is therefore important that the influence of these remedial works on the hazard at a cutting is taken into account. The most important elements of existing remedial works in relation to hazard reduction are as follows:

a. Percentage of hazards addressed by remedial works
b. Percentage effectiveness of the works in reducing hazard.

3.4 Traffic Factors

The volume and behaviour of traffic on a road have an influence on the hazard posed by a rock fall. The most important traffic factors are vehicle speed and traffic volume both of which need to be considered in the context of the speed flow relationships for the relevant class of road. Obviously a rock fall incident on a road which carries traffic volumes near its design capacity is likely to be more serious or at the very least more inconvenient and costly than one on a quiet road.

It is clear from the preceding sections that determining the hazard presented by a rock slope is likely to be complex given the large number of factors influencing the hazard and the likely complex relationships that exist between many of these factors. How this has been achieved is described later in this report. Firstly however it is necessary to consider the objectives and requirements of a hazard assessment system for highway rock slopes.

4 Objectives and Requirements

The primary aim of this research was to develop a system of assessing risk on rock slopes to allow more effective management of the rock slopes on the Scottish Trunk Road Network. However as already stated the systems developed for this research have been termed Hazard assessments to prevent confusion with quantitative risk assessment methods.

For a system to be an effective management tool it must be proactive rather than reactive. It must also provide the basis for priority based budgeting. To achieve these aims it is necessary for the system to be applied to most if not all rock slopes on the Trunk Road Network. Given the large numbers of cuttings involved, the system must involve a rapid assessment stage so that application to the whole network is not prohibitively expensive. The system should also categorise the cuttings on the basis of future action.

To achieve these requirements a two stage approach has been developed which is described in the following sections.

5 Rock Slope Hazard Index and Rating

5.1 Overview

The first stage involves deriving a Rock Slope Hazard Index from a rapid field assessment. Rock slopes are classified into one of four action categories based on the value of this index. This index acts as a coarse sift, eliminating low hazard slopes from the more detailed assessment stage. Such detailed assessment involves derivation of a Rock Slope Hazard Rating and can be carried out on a priority basis as budgets allow. Rock slopes are placed into one of three action categories based on the value of this Rating. The relationship between the Hazard Index and Rating is illustrated in Figure 4.

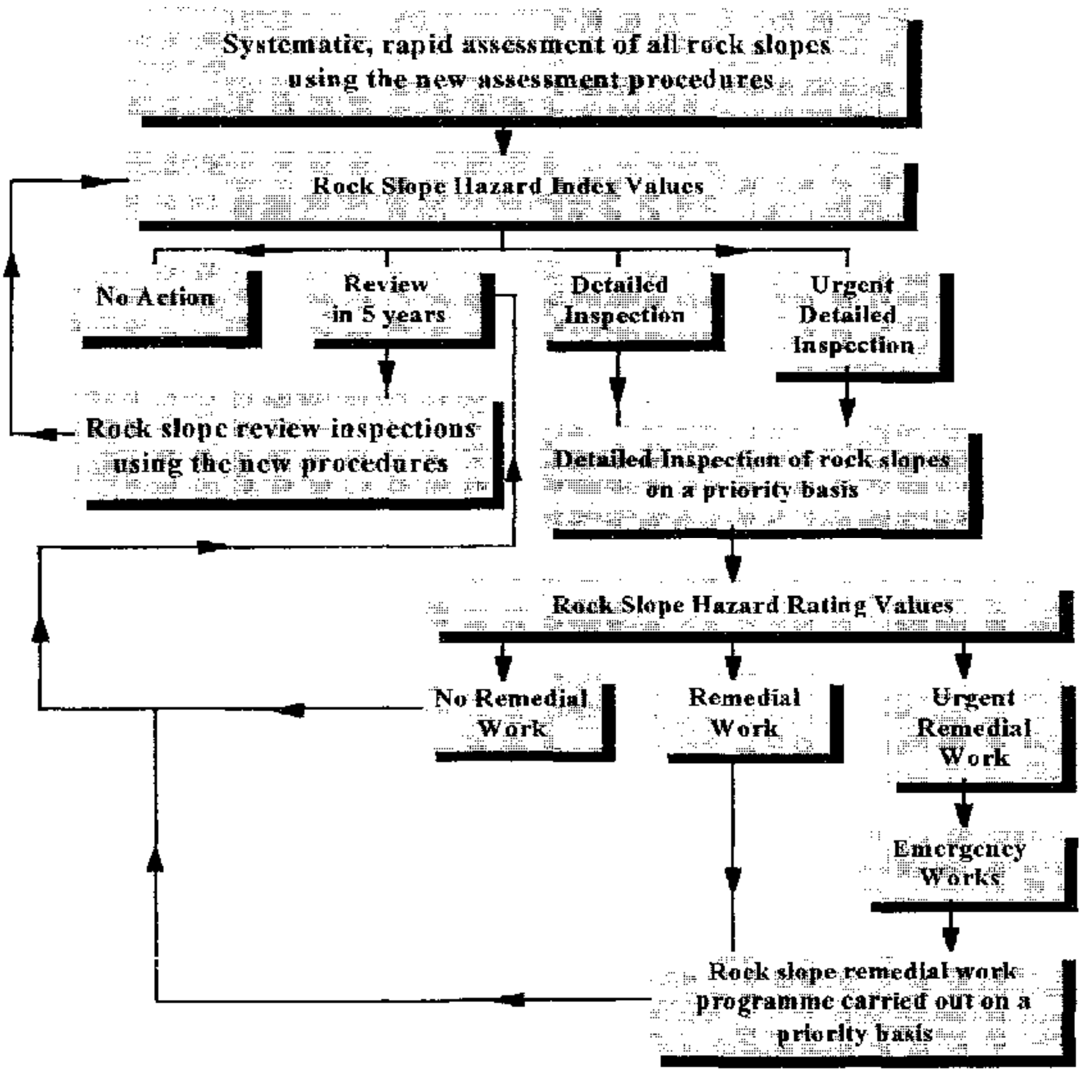

Figure 4. Proposed Rock Slope Hazard Index and Rating Systems

The Rock Slope Hazard Index and Rating systems are described in detail in the following sections.

5.2 The Rock Slope Hazard Index

The Rock Slope Hazard Index is a method of estimating the hazard presented by highway rock slopes. The system is based around rapid, standard field data collection in which estimates of influential geotechnical, geometric and remedial work factors are recorded on a standard form. There are a number of options for each factor and the relevant option is selected based on visual assessment of field conditions.

Parameter values have been derived for each input factor option. These parameter values reflect the influence that the input factor options are likely to have on rock slope hazard.

It is not possible to collect the necessary data for a probabilistic risk analysis by a rapid data collection process. The Index is therefore derived by following a standard calculation procedure using parameter values as input. The calculation process follows a logical route dictated by the influence of parameters on rock slope instability and rock fall hazard. The Rock Slope Hazard Index values derived from these calculations are used to prioritise future action through classification of slopes into four action categories as follows:

Rock Slope Hazard Index Value	Action Category
<1	1. No Action
1 -10	2. Review in Five Years
10 - 100	3. Detailed Inspection
>100	4. Urgent Detailed Inspection

The Rock Slope Hazard Index is intended to act as a coarse sift. Slopes with an Index of less than 1 do not present a hazard to the road or road user and therefore fall into the No Action category and require no future maintenance. An Index of between 1 and 10 indicates that conditions at a rock slope are such that hazards may develop in the future. These slopes therefore fall into the Review in Five Years category. Slopes in this category require only minimal maintenance commitment as the review will take the same form as the initial Hazard Index survey and will be rapid.

An Index of greater than 10 indicates that conditions at a rock slope may present a hazard to the road and road users. These slopes therefore require action to investigate the nature and severity of the hazard. Prioritisation of action is achieved by grouping these slopes into two categories of Detailed Inspection and Urgent Detailed Inspection. Slopes in these categories may require significant maintenance commitment. Firstly they require a detailed inspection and secondly this detailed inspection may reveal the need for remedial action to reduce hazards to an acceptable level.

The various elements of the Rock Slope Hazard Index are discussed in detail in the following sections.

5.2.1 Input Parameters and Data Collection

The input parameters for the Rock Slope Hazard Index were derived from published information on factors which influence rock slope instability and from the personal experience and specialist knowledge of the staff at TRLS. A list of these parameters is as follows:

a. Failure potential (plane wedge and toppling) from discontinuity - slope

b. Geometry relationships

c. Potential failure observation (plane, wedge, toppling, ravelling) Factor of safety

d. Discontinuity principle spacing, trace length and dilation Potential failure size and position on rock slope

e. Rock material strength

f. Rock weathering

g. Ground water

h. Rock trap size and shape Slope profile and berms Carriageway width

i. Sight lines

j. Cutting type

k. Associated hazards (steep slopes, buildings, services, open water) Remedial works

l. Traffic volume

The derivation of the Hazard Index from these parameters is illustrated in Figure 5.

Geotechnical factors were taken as the starting point in considering input parameters for the Rock Slope Hazard Index as these control rock slope instability. Matheson (1983) published relationships between discontinuity orientation and rock slope geometry that give rise to the three main forms of rock slope instability, namely plane, wedge and toppling. These relationships were used to derive parameter values for potential failure.

Determining the mode of potential failures on a rock slope normally involves collecting discontinuity orientation measurements and processing these together with slope orientation and bulk friction values. This is relatively slow and would require several hours per cutting to collect the data. An alternative approach was therefore developed. This involves estimating the mean dip and azimuth of joint sets present in a rock slope and the rock slope angle within the predetermined ranges shown in Table 2.

Table 2

Parameter	**Field Data Options**				
Dip	<30°	30° - 45°	45° - 60°	60° - 70°	70°_90°
Azm	Within 20°	20° - 90°	>90°		
Slope angle	<30°	30° - 45°	45°_70°	70° - 90°	

The joint set dips and rock slope angle are estimated relative to the horizontal and joint set azimuths are estimated relative to the rock slope azimuth and are recorded as positive (clockwise relative to slope) or negative (anticlockwise relative to slope). These data can be used to derive a probability that a given failure mechanism (plane, wedge or toppling) will be satisfied (see Section 5.2.2.1).

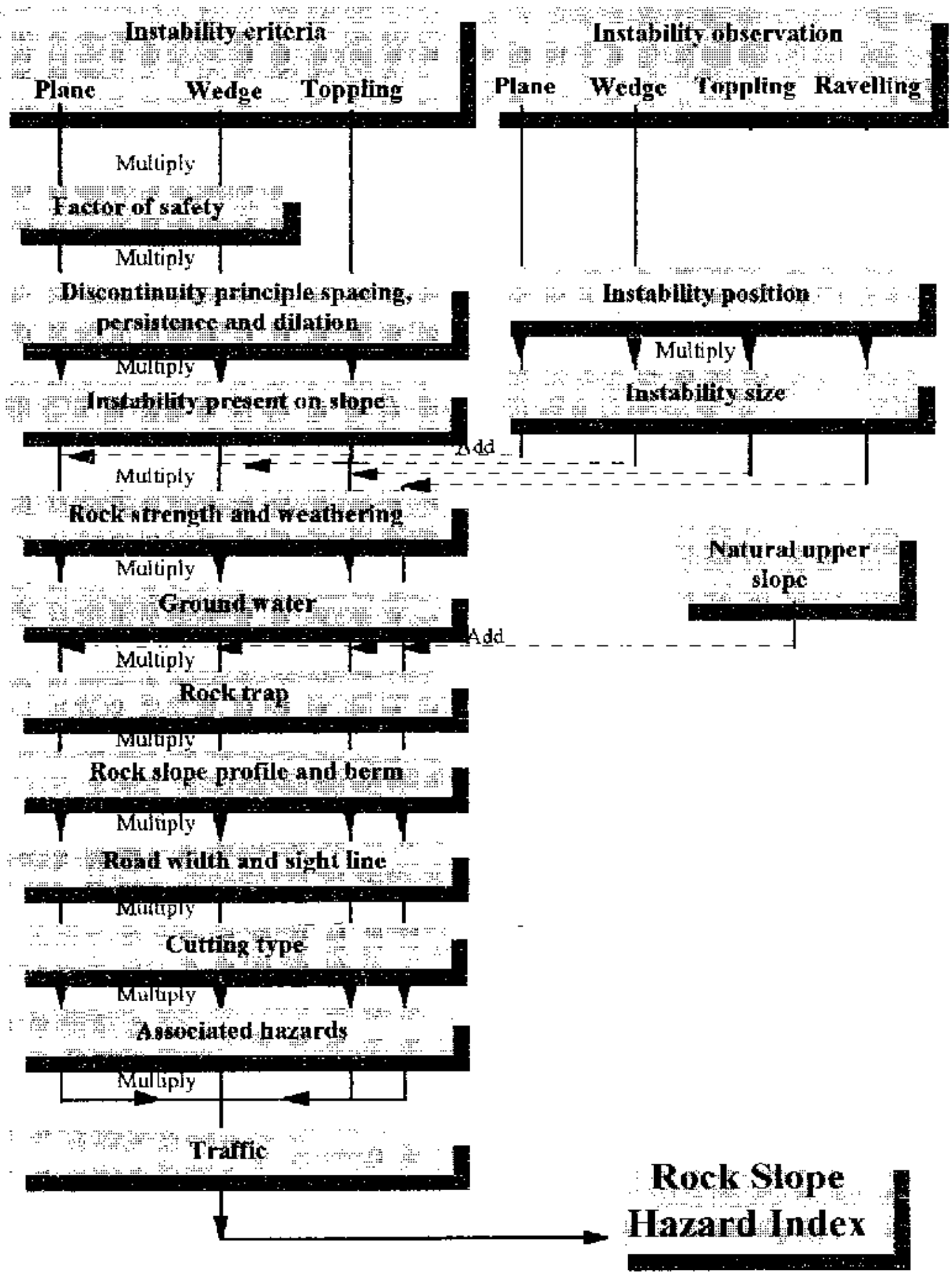

Figure 5. Derivation of the Rock Slope Hazard Index

Relative azimuth ranges for discontinuities were selected to tie in with limiting criteria for the three types of failure. Plane failure is most likely when discontinuity azimuth is within 20 degrees of slope azimuth. Wedge failure can occur when two joint sets intersect to form an intersection line that daylights on the slope. For the purposes of the Hazard Index it was assumed that most wedges will be formed by the intersection of two joint sets with relative azimuths of 20 to 90 degrees clockwise and 20 to 90 degrees anticlockwise. This is not strictly true but is considered to be a reasonable assumption for an initial evaluation of potential wedge failure hazard.

Toppling failure is a more complex situation and can be caused by discontinuities with relative azimuths in any of the ranges.

Dip ranges of discontinuities were selected partly to tie in with typical ranges for. the different types of instability and partly for ease of estimation in the field.

In some situations local potential failures may exist on a slope without the classical discontinuity and slope geometry relationships being satisfied for the whole slope. In others potential failures may be absent despite the presence of unfavourable discontinuity and slope geometry relationships. To cater for these situations it was considered necessary to have a parameter which dealt with observed potential failure on a slope (Figure 5). In this case there are four types of failure, plane, wedge, toppling and ravelling.

The severity of hazard presented by potential instability is dependent on the likelihood and consequences of failure. Therefore initial stability parameters are factored by other parameters that influence the likelihood and consequences of failure.

Factor of safety (FoS), discontinuity extent, spacing and dilation parameters influence the likelihood of failure. The FoS parameter is based on the geometry of potential failure. For plane and wedge type failure an estimate of FoS can be calculated from mean failure plane and slope angles (as long as a friction angle is assumed, and cohesion and water pressure are assumed to be zero). Because this FoS is independent of failure size it need only be calculated once for each group of potential failures as defined by the failure plane and slope orientations.

Calculation of FoS for toppling failure cannot be calculated independent of failure size and requires detailed measurements of the geometry (height, width, depth, slope face angle and failure plane angles) of each potential failure. Collection of such detailed measurements for toppling failures and the subsequent calculations of FoS would be time consuming and inappropriate for a rapid survey technique. Therefore FoS parameters are not applied to toppling failure but a compensating factor is introduced into the calculation path (see Sections 5.2.2.1 and 5.2.4.2).

Estimated mean values of discontinuity parameters are recorded from field observations in predetermined ranges as shown in Table 3.

Table 3

Parameter	Field Data Options				
Principle	<0.1m	0.1 – 0.3m	0.3 – 0.6m	0.6 - 2m	>2m
Trace Length	<1m	1 – 3m	3 - 5m	50 – 10m	>10mm
Dilation	Tight	<2mm	2 - 5mm	>5mm	

The ranges for principle spacing and trace length have been derived with reference to the Geological Society Working Party paper on the description of rocks for engineering purposes (Anon 1977). The ranges for dilation have been selected from subjective judgement of the influence of this parameter on instability. Principle spacing and trace length are recorded for each joint set as these properties are set specific. Dilation is recorded for the rock slope as a whole as it is influenced by the stability of the slope and excavation method.

The occurrence, position and size of potential failures influence the severity of the hazard posed by a rock slope. The types of potential failure observed on rock slopes are recorded and the position and size of these are estimated from visual assessment and recorded in one of the categories shown in Table 4.

Table 4

Parameter	Field Data Options		
Position on face	High	Medium	Low
Failure Size	< 1m^3	1 - 3 m^3	>3

The higher a potential failure is on a rock slope the higher the potential energy. Potential failures high on a slope therefore present a greater hazard than those low on the slope. Large potential failures are more likely to reach the road and present a greater obstacle once on the road than small failures. Large potential failures are therefore are a greater hazard than small failures.

Rock strength, weathering and groundwater flows influence the likelihood of failure and are estimated from visual assessment and recorded in the following categories:-

Table 5

Parameter	Field Data Options				
Strength	Weak	Mod. weak	Mod. strong	Strong	V.strong
Weathering	Residual	High	Moderate	Slight	Fresh
Ground Water Flow	None	Slight	Strong	V.strong	

To take account of the possibility and consequences of instability on the slope above the main rock face a parameter for the angle of the slope above the rock face was introduced. This is estimated from visual assessment and recorded as one the categories shown in Table 6.

Table 6

Parameter	Field Data Options				
Angle of slope above rock face	<20°	20° - 30°	30° - 45°	45° - 60°	>60°

Rock traps reduce the hazard associated with rock failure by preventing failed material from reaching the carriageway. Rock trap parameters are derived for each slope from relationships between verge width, ditch width and depth, fence height, slope height, slope angle and failure size. Verge width, ditch width and depth, distance to fence, fence height and slope height are estimated from visual assessment and recorded as one of the categories shown in Table 7. Slope angle is recorded as one of the categories shown in Table 2.

Table 7

Parameter	Field Data Options				
Verge width	<O,5m	0.5 - 1m	1 - 2m	2-4m	4-6m	>6m
Ditch depth	<O,5m	0.5 – 1m	1- 2m	>2m		
Ditch width	<O,5m	0.5 – 1m	1- 2m	2-4m	4-6m	>6m
Fence height	<O,5m	0.5 – 1m	1- 2m	>2m		
Dist. to fence	<O,5m	0.5 – 1m	1- 2m	2-4m	4-6m	>6m
Slope Height	<2m	2 - 5m	5 - 10m	10 - 20m	>20m	

Rock slope profile and berm width both influence the trajectory of failing material and thereby influence the level of hazard posed by a failure, These parameters are recorded in the categories shown in Table 8,

Table 8

Parameter	Field Data Options			
Profile	Even	Rough	V. rough	
Berms	None	<2m	2 - 4m	>4m

Categories for berm width were chosen to reflect the influence of berms on hazard. Berms of less than 2m width will generally increase hazard by deflecting blocks, berms between 2 and 4m wide will deflect some blocks and retain others and have therefore been assumed to have a neutral effect and berms greater than 4m wide will generally reduce hazard by retaining most blocks failing from above,

Carriageway width, sight lines, cutting type and associated hazard parameters all influence the likely consequences of a failure, These parameters are recorded in the categories shown in Table 9.

Table 9

Parameter	Field Data Options					
Carriageway width	<6m	6 - 8 m	>8m			
Sight Lines	<40m	40 - 60m	60 – 100m	>100m		
Cutting type	Box	Side long				
Associated Hazards	Steep slope opposite	Loch opposite	Building opposite	Road above	Building above	Services above

The categories for associated hazards are not mutually exclusive as it is possible to have some or all of these at a single slope.

Remedial works are designed to reduce the hazard from rock slope instability. This reduction is deemed to be proportional to the percentage of hazards treated by the works and the effectiveness of the works in treating the hazard. To reflect this there are two remedial work parameters for each type of potential failure present on a rock slope. The first of these relates to the percentage of hazards from each failure mode that are treated by the remedial work and the second relates to the effectiveness of these works. These parameters are visually evaluated and recorded in the categories shown in Table 10.

Table 10

Parameter	Field Data Options				
Amount Treated	<25%	25 - 50%	50 -75%	75 - 90%	>90%
Effectiveness	<25%	25 - 50%	50 -75%	75 - 90%	>90%

Other remedial work details are recorded during field inspection but are not used directly in calculation of the index. However, they provide useful data on the type and effectiveness of remedial works applied throughout the Trunk Road Network.

Traffic volume on a road influences the hazard presented by potential failure by influencing the probability that a failure will result in a vehicle incident. Traffic volume data is recorded by automatic traffic counting devices and current data can be recovered for the sections of trunk road in a particular survey.

The Hazard Index data collection procedure uses three standard forms, one each for geotechnical, topographic and existing remedial work data (Appendix 1). The forms are completed in the field by visually estimating the value of parameters and then selecting the relevant options from the choices on the form. These choices correspond to the options for the parameters outlined earlier in this Section (See Tables 2 to 10 and Appendix 1). This is a rapid process and even in geotechnically complex rock slopes can be carried out in less than 30 man minutes. It is, therefore, possible to complete data collection for a minimum of 14 rock slopes in a single man day. The value ranges for each parameter are presented later in this section. Data collection for the Hazard Index also includes photographic records of the rock slopes. These provided a factual reference for the cutting at the survey date and provides a check on factual accuracy of field data. The photographic records of the rock slopes are also useful in confirming the identity of slopes

An important element of field data collection for the Hazard Index is location referencing of rock slopes. It was decided, after consultation with SOID, that the Trunk Road Link and Section reference system should be adopted for this purpose.

5.2.2 Parameter Values

Determining numerical values for each parameter influencing rock slope hazard was a difficult task. A range of values were determined for each parameter reflecting the range of influence of the parameter on rock slope hazard. In general each data input category was allocated a corresponding parameter value. However in some situations (initial failure mode values and rock trap values) parameter \ values were calculated from more complex relationships. Parameter values were also required to reflect the relative importance of parameters in influencing the hazard.

As far as possible established published relationships and trends have been used in deriving parameter values. However because of the pioneering nature of this work this was not always possible and some values have been derived from the experience and expertise available at TRLS.

There are two types of parameter used to derive the Rock Slope Hazard Index, Primary parameters and Secondary parameters. Primary parameters establish the potential for failure and Secondary parameters influence the likelihood, severity and consequences of failure. There are three sets of Primary parameter values in the Hazard Index, those related to the discontinuity - rock slope geometry relationships, those related to the potential failure observations and those related to the potential for failure on the natural slope above the cutting. Primary parameters are additive in that they influence the derivation of the index by addition.

Secondary parameters influence derivation of the Index by multiplication. A parameter value of unity indicates a neutral effect on hazard. A value of greater than unity indicates that the parameter increases hazard and a value of less than unity indicates that the parameter decreases hazard.

The complete parameter value library for the Rock Slope Hazard Index is presented in Appendix 2 of this report. The value ranges for each parameter are discussed below.

5.2.2.1 Geotechnical Parameters

Potential failure criteria parameter values

The probability of plane, wedge and toppling failure criteria being satisfied can be calculated from the value ranges of discontinuity dip and azimuth, and rock slope angle as recorded on the field data forms. Plane failure is most likely to be caused by discontinuities with a azimuth of + or – 200^o relative to the slope and with a dip between the friction angle (assumed as 30^o) and the slope angle. The probability that discontinuities in the + or – 200^o azimuth category satisfy the dip criteria of greater than 30° and less than the slope angle, was calculated for all combinations of the dip and slope angle data input options.

For wedge and toppling failure the probabilities of satisfying failure criteria for combinations of discontinuity dip and azimuth options, and slope angle options, were estimated by rigorous analyses in which large numbers (between 1225 and 4100) of possible geometry combinations were generated. In each case those combinations satisfying the criteria for wedge or toppling failure were expressed as a fraction of the total number of combinations. This fraction was used as the parameter value.

These probability values are indicative of the potential for failure and have therefore been used as the Primary parameter values for plane, wedge and toppling failure. The complete set of values are presented in Appendix 2.

Factor of Safety parameter values

Factor of safety (FoS) is widely used as an indicator of the likelihood of failure in both soil and rock engineering. As indicated previously, calculation of FoS for plane and wedge failure is a relatively simple matter provided some basic assumptions are made (see Section 5.2.1). Calculation of FoS for toppling failure is a more complex problem and was considered incompatible with a rapid assessment technique. The FoS parameter values for plane and wedge failure were calculated as the inverse of the FoS as follows:

Plane failure (after Hoek and Bray 1981):

$$FoS = \frac{c.A\,(W.Cosj - U - V.Sinj)Tan\emptyset}{\mathrm{W.Sinj+v.Cosj}} \qquad \text{Equation 1}$$

Where

c = cohesion
A = Area of failure plane to which cohesion applies
W = weight of failure
V = force due to water pressure in the tension crack
U = force due to water pressure on failure plane
j = dip angle of failure plane
∅= angle of friction on failure plane

Assuming that c, V and U are zero the equation simplifies to:

$$FoS = \frac{Cosj.Tan\emptyset}{\mathrm{Sinj}} \qquad \text{Equation 2}$$

F0S parameter value = 1/FoS

Wedge failure (after Hoek and Bray 1981):

$$FoS = \frac{Sin\beta.Tan\emptyset}{\mathrm{Sin(0.5f).Tanj}} \qquad \text{Equation 3}$$

Where

β= Angle of tilt of the wedge

$\emptyset$= angle of friction on failure plane
j = dip angle of failure plane
f= Included angle of wedge

F0S parameter value = 1/FoS

In calculating the FoS the mean angles within each range were used. The table of FoS parameter values is presented in Appendix 2. FoS is a Secondary parameter.

Discontinuity principle spacing parameter values

Principle spacing influences the rock slope hazard only if the discontinuity set to which it relates contributes to the potential for instability. As the principle spacing decreases the number of discontinuities within a given length of cutting increases. The potential for formation of unstable masses therefore increases. The relationship between principle spacing and hazard was assumed to be inversely linear.

Values for the discontinuity principle spacing parameter were determined on an inverse linear scale. The category of 0.3 - 0.6m was set as unity based on subjective judgement and a sensitivity assessment in which the category fixed as unity was varied and the influence on hazard evaluated. The values for the other categories were then calculated by comparing the mean principle spacing for each category with that for the 1 - 3m category and taking the inverse as illustrated below:-

The mean principle spacing in the 0.3 - O.6m category is 0.45m. The mean principle spacing in the 0.1 – 0.3m category is 0.2m. The parameter value for the category 0.1 - 0.3m was calculated by dividing 0.2 by 0.45 and taking the inverse which gives a value of 2.25.

Discontinuity principle spacing parameter values are only used in calculation of the Index where they relate to discontinuity sets that contribute to potential instability as determined from the data collection form. This is a Secondary parameter.

Discontinuity trace length parameter values

Trace length influences the hazard posed by rock slopes only if the discontinuity set to which it relates contributes to the potential for instability. Discontinuity trace lengths provide a measure of the minimum extent of discontinuities. The int1uence of discontinuities on instability is likely to vary as a function of the surface area of the discontinuities. As the area increases so does the influence of the discontinuity on the hazard. For the purposes of the Index it has been assumed that the square of the mean trace length of a discontinuity set can be used as an estimate of the mean area of discontinuities from that set.

Discontinuity trace length parameter values are related to the square of the mean trace length. The category of 1 - 3m was set as unity based on subjective judgement and a sensitivity analysis in which the category fixed as unity was varied and the influence on hazard evaluated. The values for the other categories were then calculated by comparing the mean discontinuity area for each category with that for the 1 - 3m category as illustrated below:

The mean trace length in the 1 - 3m category is 2m therefore the mean discontinuity area for this category is $4m^2$ The mean trace length for the category 3 – 5m is 4m therefore the mean discontinuity area for this category is $16m^2$. The parameter value for the category 3 – 5m was calculated by dividing 16 by 4 giving a value of 4.

Discontinuity trace length parameter values are only used in calculation of the Index where they relate to discontinuity sets that contribute to potential instability as determined from the data collection form. This is a Secondary parameter.

Discontinuity dilation parameter values

As discontinuities become more dilated there is a progressive reduction in contact between the two sides and some surface roughness features no longer act as keys. The shear strength of the discontinuity is therefore reduced and the potential for failure increased with a corresponding increase in the Hazard.

In the absence of published data, parameter values for discontinuity dilation were attributed based on subjective judgement of the influence of dilation on hazard. No dilation or tight was given a value of unity and the parameter value increases with dilation. Discontinuity dilation is a Secondary parameter.

Potential failure observation parameter values

The failure potential indicated by failure criteria being satisfied may or may not be realised on a rock slope. In addition potential failures may occur on rock slopes where failure criteria are not satisfied. To account for these situations in the Index it was necessary to consider the occurrence of potential failures on rock slopes.

If failure criteria are satisfied and potential failures are observed on a slope the failure criteria hazard is confirmed. If, however, failure criteria are satisfied and no potential failures are observed this may be because there are no potential failures on the slope or because they are not visible from road level. In this latter situation the hazard mayor may not be present.

If failure criteria are not satisfied but potential failure is observed on a slope a hazard exists that was not predicted by the failure criteria. If failure criteria are not satisfied and no potential failures are observed it is assumed that no hazard exists.

To take account of the various situations described in the preceding paragraphs potential failure observation parameters are included in deriving the index. There are two of these parameters for plane, wedge and toppling failure. One is a Primary parameter and the other a Secondary parameter. The Secondary parameter acts on the result of the discontinuity geometry calculations for plane, wedge and toppling failure (see Section 5.2.3.2). Values were attributed to these parameters to try and account for the various situations as described in the following paragraphs.

For observed potential plane and / or wedge failures the values of the relevant Primary and Secondary parameters were set at 1. For observed potential toppling failures the Primary parameter value was set at 2 and the Secondary parameter value at 1. Increasing the Primary parameter value for potential toppling failure was to compensate for the lack of an FoS parameter for this type of failure (see Section 5.2.1).

For no observed potential plane, wedge or toppling failures the values of the relevant Primary parameters were set at zero and those of the Secondary parameters at 0.5.

There is only one potential failure observation parameter for ravelling failure. This is a Primary parameter. This parameter was allocated a value of 2 for situations where potential ravelling failure is observed and a value of zero where it is not observed. The value for observed potential toppling failure is greater than the values for potential plane and wedge failure to compensate for the lack a failure criteria parameter for this type of failure.

Failure position parameter values

The position of an observed potential failure on a rock slope influences the potential energy of the failure. The higher the potential failure on the slope the higher the potential energy and therefore the higher the potential for the failure to reach the road.

Parameter values for failure position were allocated based on subjective judgement of the influence this may have on rock fall hazard. The medium category was selected as unity. A low category has a value of below unity and high has a value of above unity (see Appendix 2). This is a Secondary parameter.

Failure size parameter values

The hazard presented by potential failures increases with increasing failure size. For the purposes of deriving parameter values, it was assumed that the increase in hazard was directly proportional to the increase in volume of the potential failure.

Failure size parameter values vary on a linear scale as a function of the volume of the potential failure mass. There are two different scales for this, one for plane, wedge and toppling, and another for ravelling. For plane, wedge and toppling the value of unity was set at the < $0.5m^3$ category. The values for the other categories were calculated by dividing the mean volume for each, by the maximum volume of the <0.5 m^3 category. For example the value for the 0.5 - 1 m^3 category is calculated by dividing the mean of this category (0.75) by 0.5 to give 1.5.

For ravelling the principle is the same as that described in the previous paragraph but unity was set at the < 0.1 m^3 category. The reason for setting unity lower for ravelling than for plane wedge or toppling is that ravelling failure often involves small block size and is also often more widespread on the rock slope than other types of failure.

This is a Secondary parameter.

Rock strength, weathering and groundwater parameter values

Rock strength, weathering and the presence of groundwater all influence the likelihood of failure. There is an inverse relationship between strength and hazard. As strength increases the likelihood of failure and the hazard decreases. There in a direct relationship between weathering and groundwater, and hazard. As weathering increases and groundwater pressures increase the likelihood of failure increases and the hazard increases.

Parameter values for strength, weathering and groundwater have been allocated based on experience and reference to published charts in Hoek and Bray (1981). The value of unity for rock strength was set at the strong and v.strong categories and the values increase with decreasing strength. The value of unity for weathering was set at the fresh and slight categories and the values increase with increased weathering.

In the case of groundwater it was assumed that flows could be taken as indicative of likely pressures. The value of unity for ground water flow was set at the none category and the values increase as the groundwater flow increases.

These are Secondary parameters.

5.2.2.2 Geometric Parameters

Angle of upper slope parameter values

Many highway rock slopes are formed in steep natural slopes that continue for some distance above the excavated cutting. In general as the angle of these natural slopes increases there is an increasing potential for instability and therefore an increase in the hazard.

In the absence of published data parameter values for the angle of slope above the rock face were allocated based on subjective assessment of the influence of this factor on rock fall hazard. The values range from 0 for < 20° to 2 for > 60°. This is a Primary parameter.

Rock trap parameter values

Rock traps reduce the hazard presented by potential failures by reducing the likelihood of the failure reaching the road. The reduction in the hazard is proportional to the effectiveness of the rock trap. There are two methods of evaluating the effectiveness of rock traps. The first considers relatively small block falls and the second considers the relationship between failure volumes and rock trap capacities.

There are two types of rock trap parameter value reflecting the two methods of evaluating rock trap effectiveness. The block fall, rock trap parameter values were derived with reference to the rock trap design guidance developed and published by Ritchie (1963), and Mak and Blomfield (1986). The effectiveness of all possible rock traps for the range of slope height and slope angle combinations that could be derived from the field data sheet options, was evaluated. Appropriate parameter values ranging from 1 to 0.001 were then allocated. A parameter value of 1 indicates an almost totally ineffective rock trap. A parameter value of 0.001 indicates a rock trap that almost totally removes rock fall hazard.

The rock trap parameter values for larger volumes of failed material were based on comparisons of calculated, likely failure volumes, the shape of failed material spoil heaps at the toe of a slope, available trap volume and distance to the road. These comparisons were carried out for all possible rock trap geometries and failure volumes that could be derived from the field data sheet options. The results were then used to evaluate the effectiveness of the rock trap and allocate an appropriate parameter value. Values varied from 1 to 0.001 reflecting the effectiveness of the trap at reducing rock fall hazard.

Complete tables of rock trap parameter values for both types of rock fall are given in Appendix 2. These are Secondary parameters.

Rock slope profile and berm parameter values

Slope profile and the size and location of berms both influence the behaviour of falling rocks. They therefore influence the hazard posed by potential failures. As slope profile becomes more uneven there is a greater tendency for falling blocks to bounce and gain horizontal momentum, resulting in more blocks reaching the road. Therefore the more uneven the slope the greater the hazard. This does not apply if the slope has a mean angle of less than 45 degrees.

Rock slope profile parameter values were derived partly from subjective assessment and experience and partly with reference to rock trap design guidance from Ritchie (1963), and Mak and Blomfield (1986). The rock trap guidance developed by Ritchie relates to bulk blasted slopes likely to have an uneven profile. The rock trap guidance of Mak and Blomfield relates to presplit slopes likely to have an even profile. Comparison of the two approaches gives an insight into the influence of slope profile on rock fall hazard. The parameter values for slope profile reflect this influence and range from unity for an even slope to 1.2 for a very rough slope.

The relationship between berm size and hazard relates to the likelihood of blocks being deflected or retained by berms. Where there is no berm there is no influence on hazard. Berms of less than 2m width will generally increase hazard by deflecting more blocks than are retained. Berms between 2 and 4m wide will deflect some blocks and retain some blocks and have been assumed to have a neutral effect on the hazard. Berms greater than 4m wide will generally reduce hazard as more material is retained than deflected. The parameter values allocated for berms reflect this logic and range from 0.8, for berms of greater than 4m, to 1.2 for berms of less than 2m.

These are both Secondary parameters.

Carriageway width and sight line parameter values

Both carriageway width and sight lines influence the likelihood of a vehicle colliding with failed rock blocks on the road and therefore influence the hazard presented by a rock slope. As carriageway width increases there is an increasing amount of space for a vehicle to swerve and avoid the blocks on the road.

In the absence of published data carriageway width parameter values have been allocated subjectively. Values range from 0.7 to 1.2, with unity set at the 6-8m category as this is the range of most modem single carriageway roads.

As the sight line on a road decreases so does the available stopping distance to an obstruction. The likelihood of a vehicle hitting a rock fall is greater for falls occurring where there are short sight lines than for falls occurring where there are long sight lines. There are two sets of parameter values for sight lines, one for single track and single carriageway roads, and one for dual carriageways and motorways.

Sight line parameter values were derived with reference to published stopping distances in the highway code. For single track and single carriageway roads unity was set at the 40 - 60m sight line category. This is the range of likely stopping distances for vehicles travelling within the speed limit on single carriageway - loads.

It was assumed that with these sight lines as many vehicles would stop before hitting a block as would hit the block therefore this range has a neutral influence- on hazard. The parameter value increases for sightlines of less than 40m as a greater percentage of vehicles are likely to hit a failure in this category. The value decreases for sight lines of greater than 60m as a greater percentage of vehicles will stop before reaching the block with sight lines of greater than 60m.

For dual carriageways and motorways the same logic applies and the category of 60 - 100m has been attributed a value of unity. This is a Secondary parameter.

Cutting type and associated hazards parameter values

Cutting type and other associated hazards such as the proximity of buildings and open water could have an influence on the outcome of a rock fall incident. The values associated with these parameters were derived by subjective assessment. These are Secondary parameters with only a small influence on the Hazard Index and values range from 1 to 1.05.

5.2.2.3 Remedial Work Parameters

Remedial works are used on rock slopes in an attempt to reduce the hazard posed by the slopes. It has been assumed that the reduction in hazard achieved by these works is proportional to the amount of the hazard treated and the effectiveness of the treatment. There are therefore two sets of remedial work parameter values, one for percentage of the hazards treated and one for the percentage effectiveness of the remedial works.

Both sets of remedial work parameter values were calculated as one hundred minus the average of the category range recorded on the field data sheet. In the case of slopes where there is potential for plane failure and between 25 and 50 percent of these failures have been treated by remedial work the percentage treated remedial work parameter was calculated as follows:

$$\{100-[(25+50)/2]\} \quad = \quad 0.625$$

The values derived from this calculation reduce the hazard index for a particular type of failure in proportion to the amount treated by remedial works and the effectiveness of the works. These are Secondary parameters.

5.2.2.4 Traffic Parameters

The influence of traffic factors on the hazard posed by a rock slope is dependant upon the volume of traffic, the traffic volume design capacity and the traffic speed, flow relationship for the road. Speed flow relationships for various classes of road are given in the COBA manual (DoT, 1985c). The design capacity of various classes of road are given in the Design Manual for Roads and Bridges (DMRB) (DoT, 1985b) and the traffic volume on a road is available from traffic counter data. Using all of these factors relationships between traffic volume and traffic parameter values were derived for the various classes of road. These are shown in graphical form in Appendix 2 of this report. These are Secondary parameters.

5.2.3 Data Analysis and Derivation of the Index

The Rock Slope Hazard Index is derived from a standard set of calculations which use the parameter values as input. The structure of the calculations reflects the influence of the parameters on rock slope hazard. The calculation process is summarised in the flowchart shown in Figure 5. The reader is referred to Appendix 3 where worked examples of Rock Slope Hazard Index calculations are presented.

The logic of derivation of the Hazard Index illustrated in Figure 5 is that Primary parameter values are derived related to the potential for each type of failure on a slope. Each type of failure is assumed to act independently and they therefore follow separate calculation paths. Calculation of the Index involves multiplying the Primary parameters by successive Secondary parameters and adding other relevant Primary parameters.

It is possible to subdivide the calculations into a number of stages which are described in the following sections:

5.2.3.1 Discontinuity Geometry Calculations

These calculations involve Primary parameter values for failure criteria, and Secondary parameter values for Factor of Safety (FoS), discontinuity spacing, extent and dilation. The calculation process is illustrated in Figure 6.

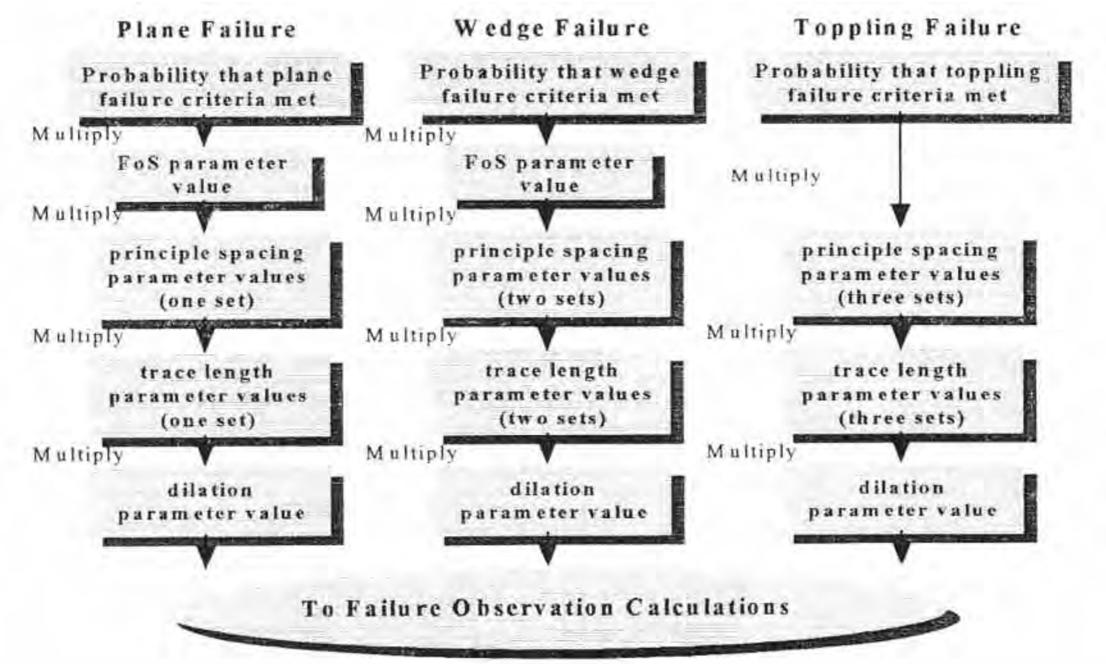

Figure 6. Discontinuity geometry calculation process

Discontinuity and slope geometry relationships are considered and where the criteria for plane, wedge and / or toppling failure are satisfied the relevant Primary parameter values for each are selected from the parameter library. If failure criteria for a particular type of failure are not satisfied then a Primary parameter value of zero is selected and the result of this part of the calculation for that type of failure will also be zero. If on the other hand the criteria are satisfied a Primary parameter value of greater than zero is selected and this is then multiplied by the Secondary parameter values for FoS, discontinuity spacing, extent and dilation.

5.2.3.2 Failure Observation Calculations.

These calculations involve Primary and Secondary parameter values for potential failure observation, and Secondary parameter values for potential failure position and size. The Primary parameter values form a second start point to the overall calculation process that is independent of the discontinuity geometry calculations (Figure 7).

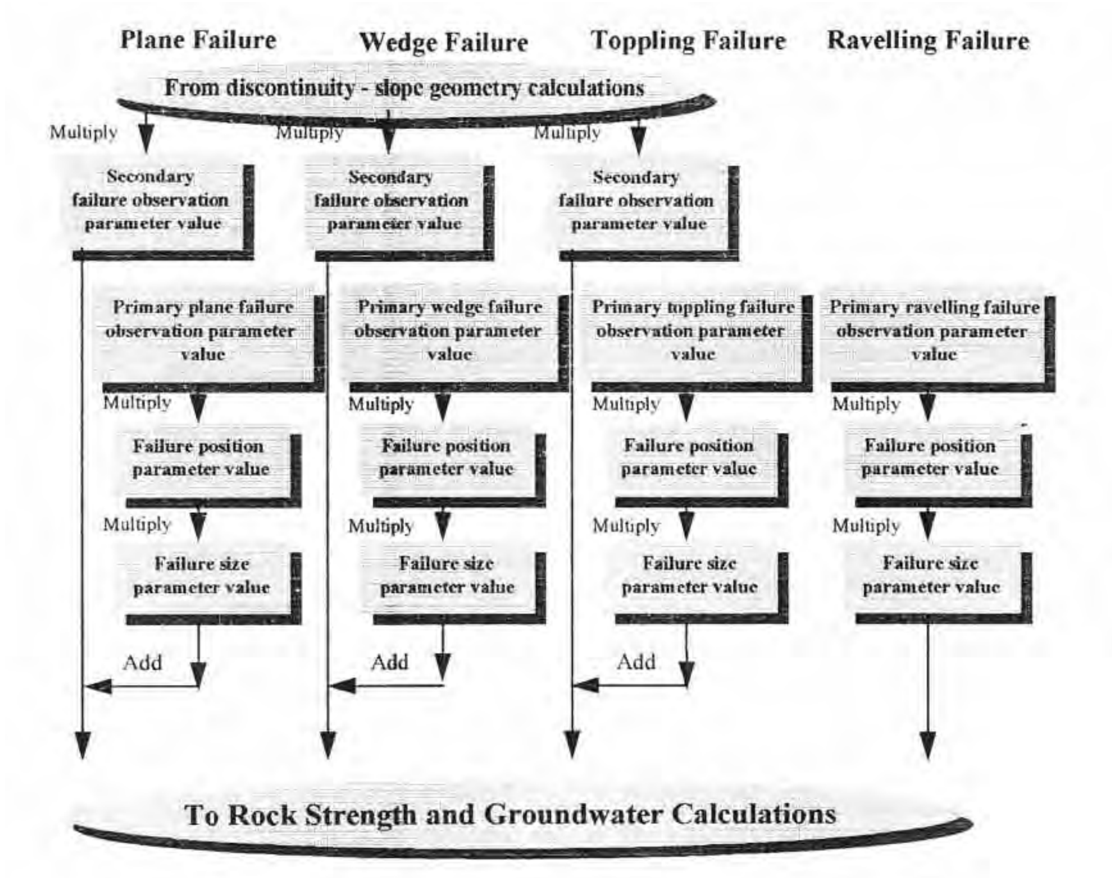

Figure 7. Potential failure observation calculation process

The Secondary parameter values for potential failure observation are selected for each type of failure. These have a value of 1 if the type of failure is observed on the slope or 0.5 if the type of failure is not observed. The results of the discontinuity geometry calculations are multiplied by these parameter values.

The Primary parameter values for potential failure observation are selected for each type of failure. These values are multiplied by Secondary parameter values for potential failure position and size. The results of this calculation for each type of failure are added to the relevant product of the result of the discontinuity geometry calculations and the slope observation Secondary parameter.

5.2.3.3 Rock Strength and Groundwater Calculations

The results of the potential failure observation calculation form the initial input values for these calculations. These initial values are multiplied by the Secondary parameter values for rock strength, rock weathering and groundwater (Figure. 8).

The result for each type of failure is termed plane, wedge, toppling or ravelling potential failure index.

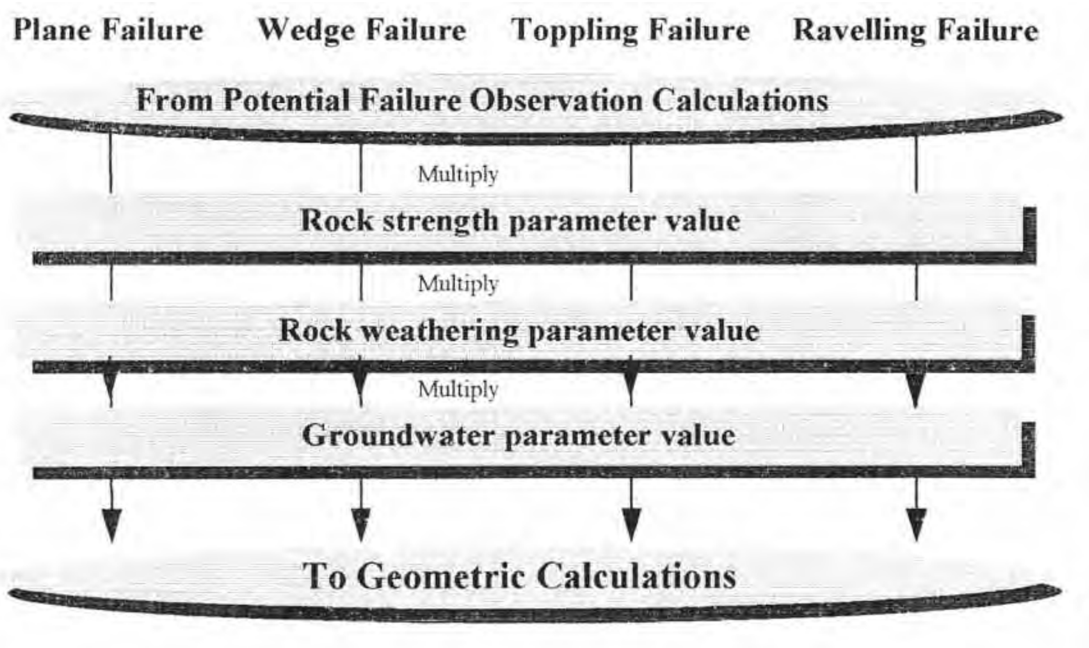

Figure 8. Rock strength and groundwater calculation process

5.2.3.4 Geometric Calculations

These calculations involve Primary parameter values for angle of natural slope above the cutting and Secondary parameter values for rock trap, slope profile, berms, carriageway width, sight lines, cutting type and associated hazards. Firstly the Primary parameter value for the angle of slope above the cutting is added to the failure index for each type of failure. The resulting values are then multiplied by the Secondary parameter values for rock trap, rock slope profile, berms, carriageway width, sight lines, cutting type, and associated hazards (Figure 9).

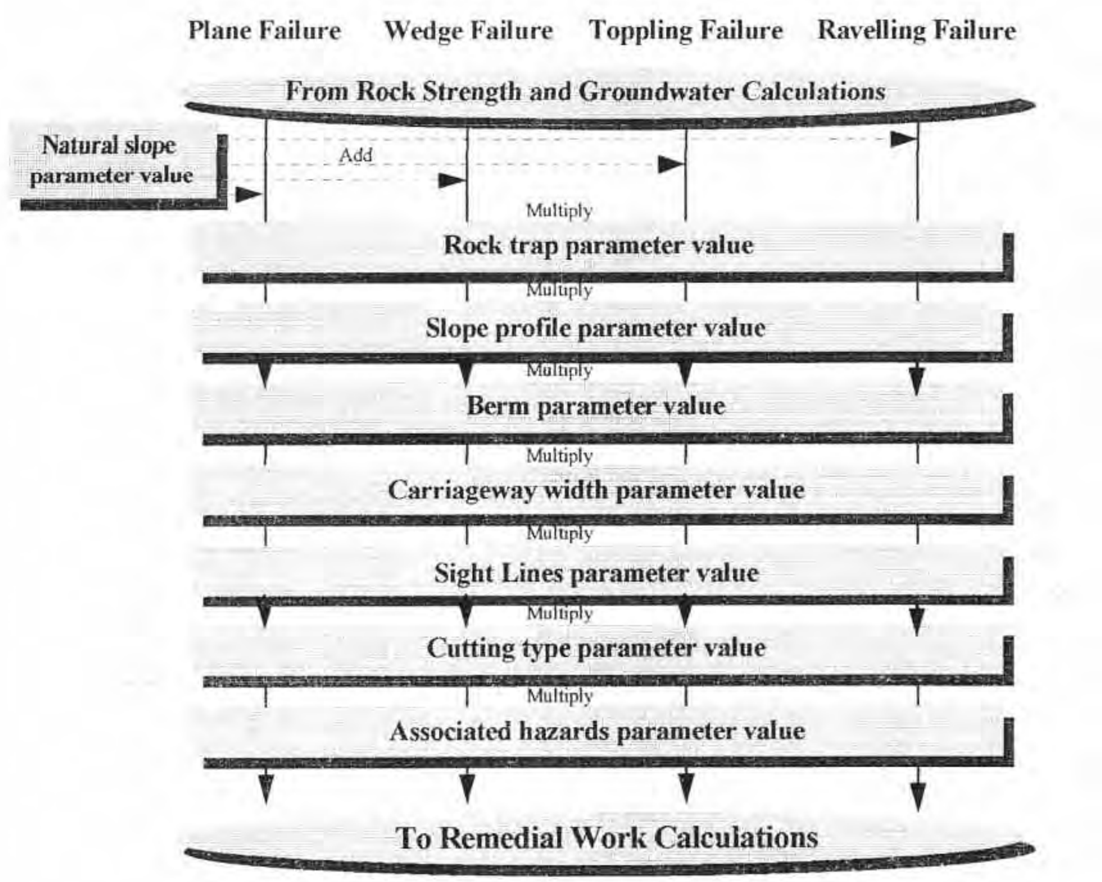

Figure 9. Geometric calculation process

5.2.3.5 Remedial Work Calculations

Remedial work calculations involve Secondary parameter values for remedial work. The results of the geometric calculation process for each type of failure are multiplied by the relevant remedial work parameter values (Figure 10).

5.2.3.6 Traffic Calculations

The final calculation in deriving the Rock Slope Hazard Index is to add together the values derived from the remedial work calculations and then multiply this resultant by the Secondary parameter value for traffic (Figure 10). The resulting value is the Rock Slope Hazard Index.

Unlike the Hazard Index, the Rating has been developed without the benefit of a field trial. As a result the system described in the following Sections has not been fully evaluated. Such evaluation is essential and will almost certainly result in some refinement of data collection, and calculation procedures and sequences. However these refinements are unlikely to alter the philosophy or logic on which the present system is based.

5.2.4 Input Parameters and Data Collection

Most input parameters for calculation of the Rock Slope Hazard Rating are failure specific and a complete set of parameters are required for each potential failure observed on the rock slope. The remaining parameters are slope or road section specific and only need to be collected once at each cutting or for each section of road. The relevant parameters are as follows:

- Potential Failure Specific
  - Potential failure plane discontinuities:
  - Dip and azimuth, trace length, roughness, planarity, strength, weathering, dilation, infill and water seepage.
  - Rock strength and weathering adjacent to potential failure
  - Potential failure dimensions:
    - height, width and depth (depth for toppling only; can be calculated for plane and wedge)
  - Rock face dip and azimuth local to potential failure
  - Height of potential failure on face
  - Profile of face below potential failure
  - Berms on face below potential failure
  - Verge width
  - Ditch width and depth
  - Distance to and height of fence
  - Sight lines
  - Remedial Treatment:- Coverage and effectiveness
- Rock Slope Specific
  - Discontinuities:
    - Dip, azimuth, trace length, planarity, dilation, infill and roughness for a recommended minimum of 10 discontinuities from each set present on the rock slope
  - Potential Ravelling Failures:
    - Number, average size, average height on face, average face profile below failures, average verge, ditch and fence dimensions.
  - Remedial Treatment: - Coverage and effectiveness
  - Carriageway width
- Road Specific
  - Traffic volume

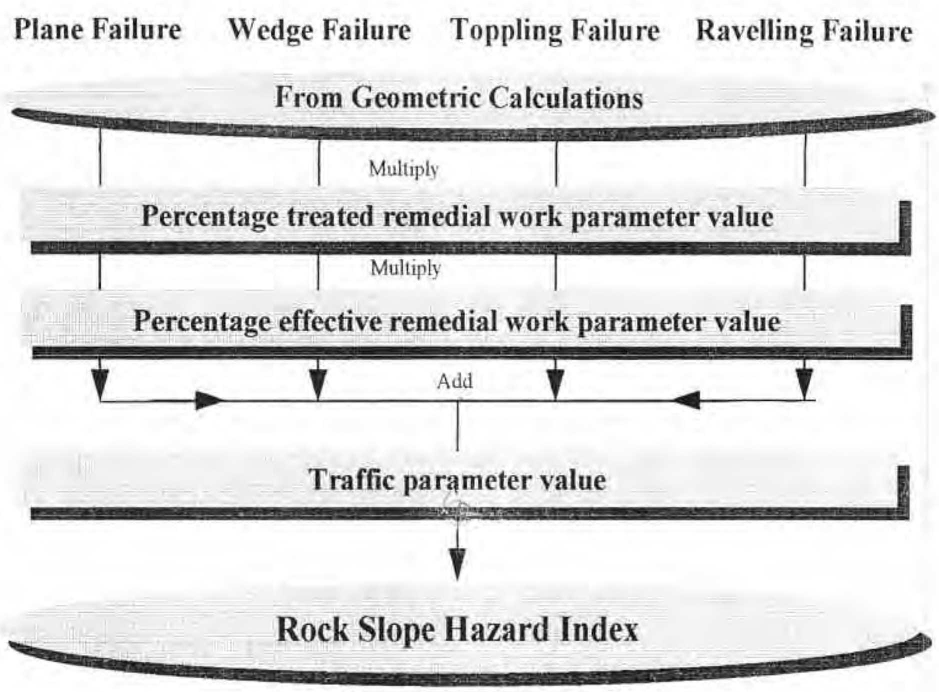

Figure 10. remedial work and traffic calculation processes

5.3 The Rock Slope Hazard Rating

The Rock Slope Hazard Rating is intended to provide a method of determining the level of hazard presented by a rock slope by considering the sum of the hazards presented by all potential failures on a slope. It is a semi-probabilistic method based upon the principles of quantitative risk analysis but without historical, statistical data to back up all of the assumptions. The analysis requires detailed field data input from each potential failure under consideration. Unlike the Index, the Rating requires actual measurements rather than estimates to be collected during the field data survey. However, as with the Index, a standard field data collection form is used to achieve consistency of approach. The Rating survey is a more rigorous and time consuming activity than the more rapid Index survey.

The Results of the Hazard Rating survey act as a fine sift allowing separation of potential instability requiring remedial work and that requiring no remedial work Those slopes requiring action are split into two action categories of Remedial Work and Urgent Remedial Work Slopes requiring no remedial work are included in the next five year review using the Index system (Figure 4).

A low Hazard Rating means that the potential hazard indicated by the Hazard Index is not realised and no remedial action is required. A high Hazard Rating means that there is a hazard to the road and road user and remedial action is advisable. The Rock Slope Hazard Ratings can be used to prioritise remedial work.

Unlike the Hazard Index, the Rating has been developed without the benefit of a field trial. As a result the system described in the following Sections has not been fully evaluated. Such evaluation is essential and will almost certainly result in some refinement of data collection, and calculation procedures and sequences. However these refinements are unlikely to alter the philosophy or logic on which the present system is based.

5.3.1 Input Parameters and Data Collection

Most input parameters for calculation of the Rock Slope Hazard Rating are failure specific and a complete set of parameters are required for each potential failure observed on the rock slope. The remaining parameters are slope or road section specific and only need to be collected once at each cutting or for each section of road. The relevant parameters are as follows:-

Potential Failure Specific

Potential failure plane discontinuities:

Dip and azimuth, trace length, roughness, planarity, strength, weathering, dilation, infill and water seepage.

Rock strength and weathering adjacent to potential failure

Potential failure dimensions:

height, width and depth (depth for toppling only; can be calculated for plane and wedge)

Rock face dip and azimuth local to potential failure

Height of potential failure on face

Profile of face below potential failure

Berms on face below potential failure

Verge width

Ditch width and depth

Distance to and height of fence Sight lines

Remedial Treatment:- Coverage and effectiveness

Rock Slope Specific

Discontinuities:

Dip, azimuth, trace length, planarity, dilation, infill and roughness for a recommended minimum of 10 discontinuities from each set present on the rock slope

Potential Ravelling Failures:

Number, average size, average height on face, average face profile below failures, average verge, ditch and fence dimensions.

Remedial Treatment: - Coverage and effectiveness Carriageway width

Road Specific

Traffic volume

The logic of how these parameters contribute to derivation of the Rating is illustrated in Figure 11.

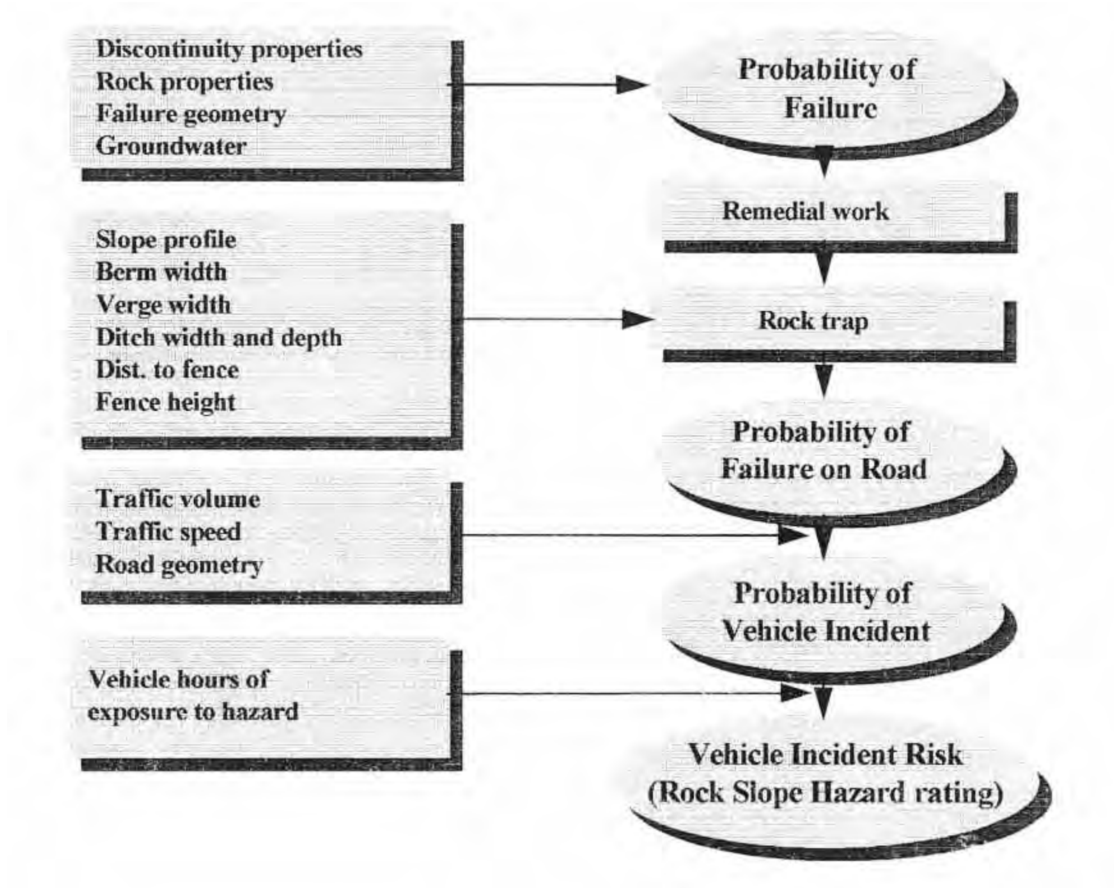

Figure 11. Schematic illustration of parameter relationships in the Rock Slope hazard Rating.

As with the Hazard Index, the Hazard Rating data collection procedure is based on standard forms. In this case there are five types of form, one each for the four types of rock slope failure and one for the discontinuity survey (Appendix 4). For plane, wedge and toppling failure one form is completed for each potential failure on the slope under investigation. There may, therefore, be several plane, wedge and toppling failure forms for each rock slope. For ravelling failure only one form is completed for the whole slope. Only one discontinuity survey form is completed for each rock slope.

The Rock Slope Hazard Rating data collection procedure involves making detailed measurements on and adjacent to each rock slope. In most cases this will involve gaining access to the rock face. As a result Rating surveys will require more site time and effort than Index surveys. The time taken for a Rating survey will be dependant on geotechnical complexity, slope geometry and, the number and location of potential failures on a slope. However it is estimated that in general between 1 and 8 man days will be required to complete a Hazard Rating survey for each rock slope.

Rock cuttings surveyed for the Hazard Rating will have a reference number and location from the Hazard Index survey.

Each slope subjected to a Rating survey will be photographed. This will allow comparison with the original Index survey photographs.

Potential failure plane discontinuity data are required for input into the probabilistic analyses used in deriving the Rating. Discontinuity dip, azimuth and trace length are recorded as actual values measured in the field. Roughness, planarity, strength, weathering, dilation, infill and water seepage are selected from the options shown in Table 11.

Table 11

Parameter	Field Data Options			
Roughness	Smooth	Rough	Very rough	
Planarity	planar	slight curved	curved	
Strength	weak	mod.weak	mod.strong	strong/ very strong
Weathering	fresh/slight	moderate	highly	completely
Dilation	tight	<2mm	2 – 5mm	>5mm
Infill	none	granular	cohesive	
Water flow	none	slight	strong	v. strong

Strength and weathering of the rock within and adjacent to potential failure masses are chosen from the options shown in Table 11 for strength and weathering of discontinuity surfaces.

Potential failure dimensions (height, width and, in the case of toppling failure, depth) are measured in the field.

Rock face dip and azimuth, height of potential failure on face, size of berms on face below failure, verge width, ditch width, ditch depth, distance to fence and height of fence are measured in the field. The profile of the face below the failure is selected from the options shown in Table 12.

Table 12

Parameter	Field Data Options		
Profile	even	rough	v Rough

Sight lines for points on the road below potential failures are estimated from visual assessment and recorded as a selection from a number of options. The options are the same as those used in the Hazard Index (see Table 9).

The type, extent and effectiveness of any remedial work used to treat potential instability is recorded. The percentage coverage and effectiveness of the remedial work are recorded using the same options as in the Hazard Index (see Table 10).

Discontinuity dip, azimuth and trace length measurements are measured as part of the discontinuity mapping. Discontinuity planarity, dilation, infill and roughness are recorded as choices from a number of options as detailed above (see Table 11).

Probabilistic assessment of potential ravelling failure is difficult as there is no simple model to use in the analysis and there are often large numbers of small potential ravelling failures on anyone slope. Analysis of individual failures is therefore impractical and ravelling failure is assessed on a slope basis. The input parameters for assessing ravelling failure hazard are chosen from the options shown in Table 13.

Table 13

Parameter	Field Data Options					
Number	<20	20 – 40	40 – 60	60 – 80	80 – 100	>100
Height of face	<2m	2 – 5m	5 – 10m	10 – 20m	>20m	
Face profile	even	rough	very rough			

Average verge width, ditch width, ditch depth, distance to fence and fence height are estimated for the whole slope and selected from the same categories as used in the Hazard Index (see Table 7).

Remedial treatment for ravelling failure is treated the same as other types of failure.

Carriageway width is recorded as the average of three measurements taken along the length of the cutting.

Traffic volume data are obtained from automatic traffic counters for the section of road under study.

5.3.2 Parameter Values

The calculations carried out to derive Rock Slope Hazard Rating values use a combination of field measurements and values attributed to parameter selection ranges. In general measurements from field surveys are used directly in calculations with no alteration. Values attributed to the other parameters have, as far as possible, been derived from published trends but in some cases are based on experience and judgement. If field or testing data, or local experience dictate the parameter values and ranges may be altered from those given in this section and listed in Appendix 5.

Dip, azimuth and trace length measurements from potential failure plane discontinuities are used in the probabilistic calculations. The measurements are used as mean values in the calculations and the range of variation about these means is determined by observations of planarity (Table 14).

Table 14

Planarity	Dip variation	Azm variation
Planar	+ or -1	+ or -5
Slightly curved	+ or -2	+ or -8
Curved	+ or -3	+ or -10

If dip and azimuth cannot be measured directly for a potential failure plane the mean values determined for the relevant set from discontinuity mapping are used in analyses. The variation is the range for that set.

Variations applied to discontinuity measurements attempt to take account of the possibility that the discontinuity is not planar behind the rock face and that the single measurement of orientation taken is not representative of the orientation of the plane over its full extent.

Measured trace lengths for potential failure planes are used to calculate minimum values for discontinuity area. Maximum values for discontinuity area are determined from the maximum trace lengths for relevant sets recorded in the discontinuity survey. This provides a range of discontinuity areas for use in probabilistic calculations.

Observations of roughness, strength, weathering and infill influence the choice of strength parameters for potential failure planes. An initial angle of friction (PHI) for the failure plane of 35° + or - 3° was adopted for an rocks unless testing data or field observations suggest otherwise. This is a widely advocated and used 'standard' range of friction angles for rock discontinuities in the absence of other data. This value is then altered by observed ranges for other parameters as shown in Table 15.

Table 15

Parameter	Option	Mean PHI variation
Roughness	smooth	0
	rough	2
	very rough	3
Strength	strong/ v. strong	0
	moderately strong	-1
	moderately weak	-2
	weak	-3
Weathering	fresh/ slight	0
	moderately	-1
	highly	-2
	completely	-3
Infill	none	0
	granular	-1 (to a min of 30)
	cohesive	Reduce to 30 unless lower

The above alterations to the friction angle are an attempt to take account of the influence of the various parameters listed above on discontinuity shear strength.

For the purposes of the Rating it is assumed that water seepage and discontinuity dilation observations can be used to estimate the water column height at a potential failure. This has been done as shown in Tables 16 and 17.

Table 16

Water seepage	Water column height
Dry	0 – 20%h
Slight	20 – 50%h
Strong	50 – 75%h
v. strong	75 – 100%h
Where h is the height of the potential failure	

Table 17

Dilation	Influence on water column height
Tight	0
<2mm	0
2 – 5mm	-30%
>5mm	-60%

The values shown in Table 17 take account of the fact that ground water is likely to be free flowing in rock with widely dilated discontinuities rather than being restricted and causing water pressure on discontinuity surfaces.

The strength and weathering of rock material in and adjacent to potential failures are used to determine and factor the cohesion value for the rock. The value of cohesion is applied where potential failure planes do not fully delimit the failure mass (see Section 5.3.3.1). The starting cohesion values are determined by the rock strength with reference to values published in Hoek and Bray (1981) and this is factored by the rock weathering as shown in the following table:-

Table 18

Parameter	Selection range	Mean tensile strength
Strength	strong/ v.strong	350kN/m^2
	moderately strong	250kN/m^2
	moderately weak	150kN/m^2
	weak	50kN/m^2
		Variation in mean tensile strength
Weathering	fresh/ slight	0
	moderately	-10%
	highly	-50%
	completely	-70%

Potential failure width, height and depth values recorded from field surveys are used directly in calculations.

Rock face dip and azimuth values local to the failure are used as measured.

Parameter values for percentage of potential instability treated and the effectiveness of remedial works, are calculated as one hundred minus the mean of the selection option range. The product of these values can be taken as the percentage of each potential failure not influenced by the remedial works. This product is used as the remedial work parameter.

Height of failure on face, size of berms below failure, verge width, ditch width, ditch depth, distance to fence and fence height values recorded in the field are used to determine rock trap parameter values. The values are estimates of the likelihood of a failure reaching the road that have been derived from rock trap design guidance by Ritchie (1963) and Mak and Blomfield (1986) and by considering the volume of the failure in relation to the capacity of the rock trap. For even slopes the guidance given in Mak and Blomfield (1986) is used to derive parameter values for uneven slopes the guidance given in Ritchie (1963) is used.

All of the above parameter values are associated with plane wedge and toppling failures and are used in detailed, failure specific probability and hazard calculations associated with these potential failures. However this approach is impractical for ravelling failure. Firstly because of the lack of a suitable deterministic failure model to use as a basis for probabilistic analysis and secondly because of the large number of potential ravelling failures that may exist on a given slope. To take account of ravelling in the Rating it was necessary to make a subjective assessment of the probability of ravelling failure occurring. For the purposes of the Rating and in the absence of any reliable data is assumed that 10% of all potential ravelling failures on a slope will fail.

Remedial treatment parameter values are derived in a similar way to other types of failure but deal with all potential ravelling failures on a rock face rather than with specific potential failures.

The height of potential failures on face, face profile, berm size, verge width, ditch width, ditch depth, distance to fence and fence height are used to determine rock trap parameter values. However for ravelling failure the values are derived for the cutting as a whole using rather than for each potential failure. The parameter values for this are the same as for other types of failure.

Sight lines and traffic volume data are used to calculate the probability that a failure that reaches the road will cause a vehicle incident. Both values are used unaltered in the calculations with no ranges applied.

5.3.3 Data Analysis and Derivation of the Rating

The Rock Slope Hazard Rating is derived from a standard set of calculations which use field measurements and parameter values as input. The structure of the calculations reflects the logic of how the parameters influence rock slope hazard. The calculation process is summarised in the flowchart shown in Figure 12.

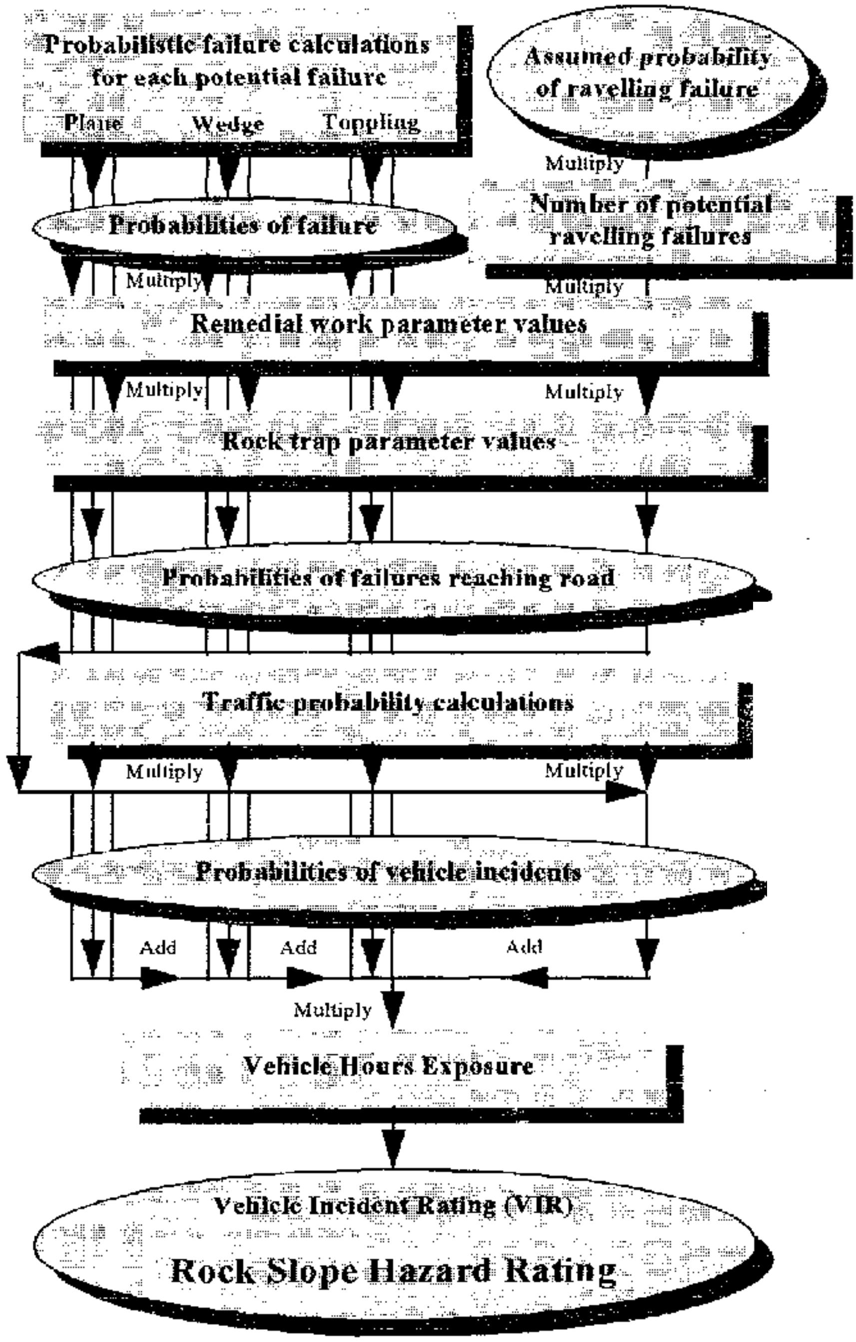

Figure 12. Schematic illustration of the Rock Slope Hazard Rating calculation process

The calculations can be divided into a number of stages as follows:-

5.3.3.1 Probabilistic Failure Calculations

Established, deterministic methods of calculating factor of safety (FoS) for plane, wedge and toppling failure are used in these calculations. By executing the FoS calculation a large number of times and varying many of the input variables though a range of values it is possible to carry out a probabilistic analysis. Each calculation derives an FoS result. Some of these results will be greater than one others will be equal to or less than one. The ratio of the number of results equal to or less than one to the total number of results can be used as a measure of the probability of failure. These calculations are carried out for each potential plane, wedge and toppling failure identified on the slope.

The equation used in the plane failure probabilistic calculations is as follows:

$$FoS = \frac{c.A+(W.Cosj-U-V.Sinj)Tan\emptyset}{W.Sinj+v>Cosj} \qquad \text{Equation 4}$$

Where (Figure 13)

c = cohesion

A = Area of failure plane to which cohesion applies

W = weight of failure

V = force due to water pressure in the tension crack

U = force due to water pressure on failure plane

j = dip angle of failure plane

∅ = angle of friction on failure plane

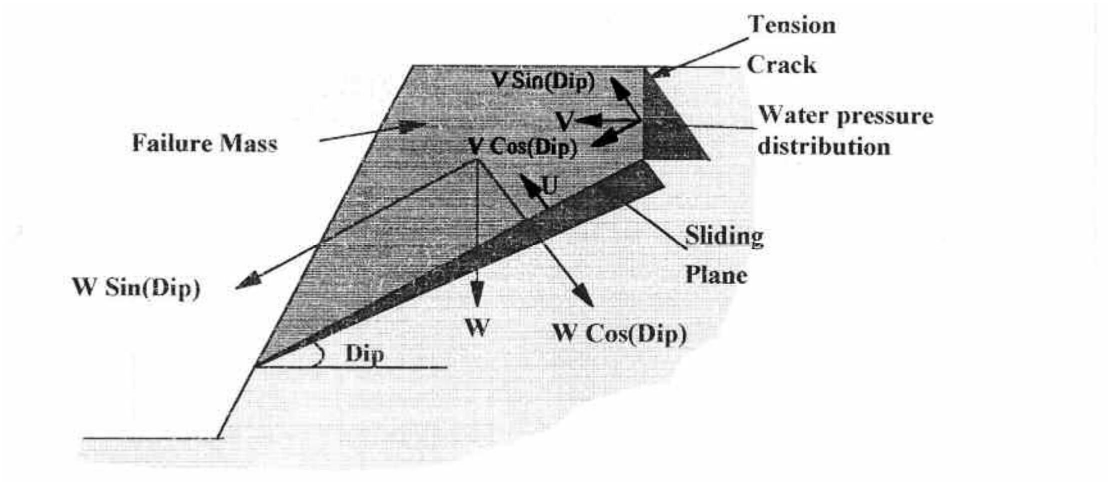

Figure 13. Model used in plane failure probabilistic analysis

The method used to calculate FoS for wedge failure is complex and has not been described in this report. A full description of the method is given in Hoek and Bray (1981).

Calculation of FoS for toppling failure involves resolving disturbing and restoring moments acting on the toppling block. The FoS is then calculated from the ratio of restoring to disturbing moments (Figure 14).

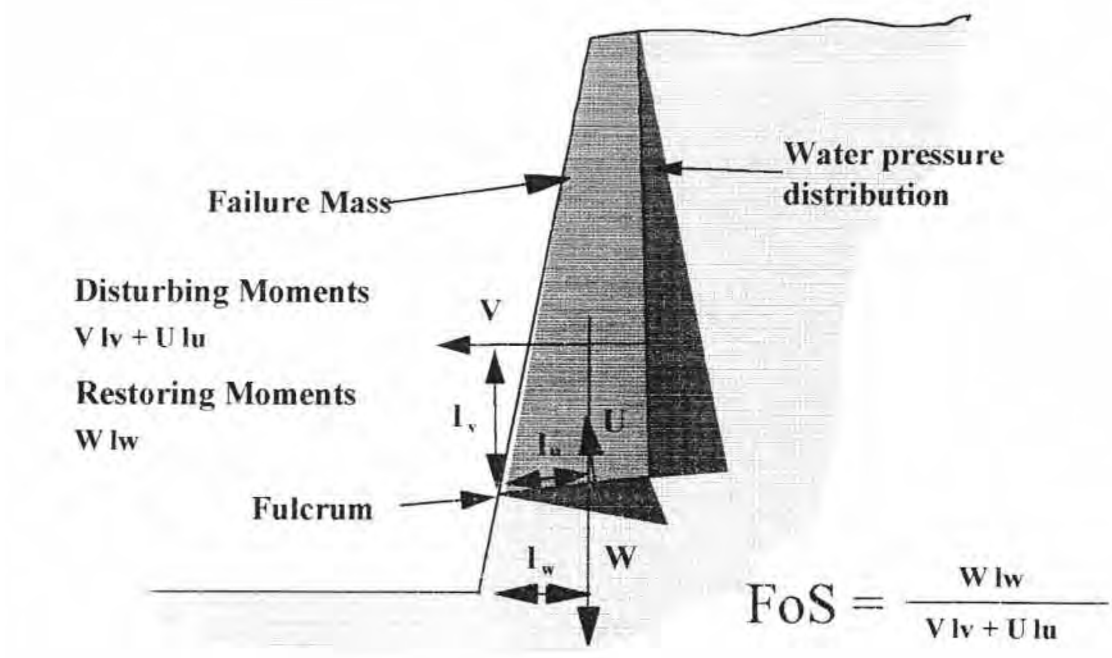

Figure 14. Model used in toppling failure probabilistic analysis

Input values for most variables for the plane, wedge and toppling probabilistic analyses are simple and are determined by field measurements and observations (see Section 5.3.2). However the calculation of effective cohesion on potential failure planes is not so simple.

If a potential failure plane completely delimits a potential failure then it is assumed that there is no effective cohesion on that plane. However, if a failure plane does not completely delimit a potential failure an area of unbroken rock will link the potential failure to the main rock mass. In this case there will be effective cohesion. It is almost impossible to determine if a potential failure plane fully delimits a potential failure mass because the subsurface part of the failure plane cannot be inspected.

An estimate of the area delimited by a potential failure plane can be made by assuming that the area of the plane is equal to the square of the measured trace length. The area of plane required to delimit a potential failure can be calculated from field measurements. If the area of a potential failure plane is greater than or equal to the required area it could be assumed that the potential failure is fully delimited. This is of course not strictly true because of shape differences. However, as calculation of the shape of potential failure planes is not possible the assumption has been adopted in the calculation process. If the area of a potential failure plane is smaller than the required area then the potential failure may not be fully delimited.

However, the extent of a potential failure plane may be much greater than the measured trace length. The area of a plane could therefore also be much greater. To account for this it is necessary make reference to discontinuity mapping data for the rock slope. The area of a potential failure plane can be varied between the square of the measured trace length and the square of the maximum measured trace length for joints belonging to that set. This will then give a range of areas over which cohesion is acting for the failure plane. The variation in total cohesion acting on a plane can then be estimated and used in the probabilistic calculations.

5.3.3.2 Ravelling Probability Calculation

This involves multiplying the mean of the observed number of failures category by 0.1 (the assumed probability that ravelling will occur).

5.3.3.3 Remedial Work Calculations

If it is assumed that the probability of failure is reduced directly in proportion to the amount of a potential failure treated by remedial works and the effectiveness of those works it is possible to estimate the probability of failure despite the presence of remedial works. This is done by multiplying the remedial work parameter value by the probability of failure. For plane, wedge and toppling this is done independently for each treated failure. For ravelling failure it is done once for the rock slope.

5.3.3.4 Rock Trap Calculations

If it is assumed that rock trap parameter values are representative of the probability that a failure will not be contained by the rock trap the probability of a failure reaching the road can be estimated. The relevant rock trap parameter values derived from field data are multiplied by the results of remedial work calculations. This gives the probability that a failure will reach the road (P_f). This is done independently for each plane, wedge and toppling failure and once for the slope for ravelling failure.

5.3.3.5 Road Geometry and Traffic Calculations

Essentially these calculations will estimate the probability that a failed rock mass will cause a vehicle incident. A rigorous calculation of this requires data on the distances at which drivers notice rock falls of various sizes on the road and their reaction to such obstacles. This data is not available at present. In the absence of data on driver awareness of rock falls, a less rigorous method of taking account of road geometry and traffic is required. This less rigorous method is described below:-

Basic traffic data in the form of traffic counter information is available for most sections of the trunk road network. Average vehicle speeds can be estimated from speed flow relationships for the type of road under study. If some basic assumptions are made it is possible to derive a number of basic probabilities from this information. The assumptions are as follows:

a. z% of the daily traffic on a road occurs between 0700 and 2100.
b. The probability of failure is independent of time of day.
c. The traffic volume per carriageway can be determined by halving the total traffic count for the road and is randomly distributed.
d. A vehicle will hit a block if it comes into sight within 40m or less.
e. A block on the road will first be noticed by a driver at a distance of 100m.

If a failed block reaches the road within 40m in front of a vehicle then the vehicle will hit the block or the block will hit the vehicle. The probability that a vehicle is within a 40m stretch of road is calculated as follows:-

The probability that a vehicle is within a 40m length of road between the hours of 0700 and 2100 hours (day period), P_{v40day}, is as follows:

$P_{v40day} = \frac{40.z.x}{14Vs}$ Equation 5

where

x = number of vehicles per day per carriageway

R_1 = length of stretch of road

V_s = average vehicle speed

z = % of daily traffic on a road occurring between 0700 and 2100 hours.

The derivation of this expression is given in Appendix 6.

If the probability of a failure reaching the road at a point is Pf then the number that reach the road between 0700 and 2100 hours (day period), P_{fday}, is as follows:

$P_{fday} = P_f.\frac{14}{24}$ Equation 6

The probability that a failure will reach the road during this day period when a vehicle is within 40m of this point and therefore will hit or be hit by the failure is given by:

$$P_{v40day}.P_{fday}$$

The probability that a vehicle will be outside this 40m stretch of road during the day period is given by:

$$1 - P_{v40day}$$

The probability that a failure will reach the road when the vehicle is outside this 40m of road during the day period is given by:

$$(1 - P_{v40day}).P_{fday}$$

If a failure occurs on a section of road where visibility to the failure is less than 40m then it will be hit by the next oncoming vehicle. Therefore for a failure where there is less than 40m of visibility the probability that a failure will cause a vehicle incident during the day period, P_{viday}, is given by:

$P_{viday} + \{(1 - P_{v40day}).P_{fday}\} + P_{v40day}.P_{fday}$ Equation 7

$$P_{viday} = P_{fday}$$

In other words if a failure occurs and reaches the road where there is less than 40m of visibility it is almost certain to cause a vehicle incident.

If a failure occurs on a section of road with visibility of better than 40m and the failure is more than 40m in front of the nearest vehicle, the probability that the vehicle will hit the failed rock is dependant on driver reaction time. As already stated data on driver reaction to rockfall are not available. We can however make some empirical assumptions relating to breaking distances in place of experimentally determined probabilities and express these as likelihood values as follows:-

Table 19

Sight lines	Likelihood values
40 – 60m	0.75 (mean of variation from 0.5 to 1)
60 – 100m	0.3 (mean of variation from 0.05 to 0.5)
>100m	0.05

If these likelihood values are taken as an estimate of the probability of hitting a failure given the corresponding sight distance they can be incorporated into the calculations as follows:-

The probability that a failure that will cause a vehicle incident, P vi day, on a section of road with sight lines of between 40 and 60m is as follows:

$$P_{viday} = 0.75\{(1 - P_{40day}).P_{fday}\} + P_{v40day}.P_{fday}$$ Equation 8

$$P_{viday} = 0.75P_{fday} + 0.25P_{v40day}P_{fday}$$

The probability that a failure that will cause a vehicle incident, P vi day, on a section of road with sight lines of between 60 and 100m is as follows:

$$P_{viday} = 0.3\{(1 - P_{40day}).P_{fday}\} + P_{v40day}.P_{fday}$$ Equation 10

$$P_{viday} = 0.3P_{fday} + 0.7P_{v40day}P_{fday}$$ Equation 11

The probability that a failure that will cause a vehicle incident, P vi day, on a section of road with sight lines of greater than 100m is as follows:

$$P_{viday} = 0.05\{(1 - P_{40day}).P_{fday}\} + P_{v40day}.P_{fday}$$ Equation 12

$$P_{viday} = 0.05P_{fday} + 0.95P_{v40day}P_{fday}$$ Equation 13

The above calculations are applied to each potential plane, wedge and toppling failure on a slope. The relevant calculation for Ravelling failure is carried out only once for the slope as a whole.

A similar set of calculations is performed to determine the probability of a failure causing a vehicle incident during the 2100 to 0700 hours or night period (P_{vingt}).

The above calculations are very simplified and do not take into account detailed traffic behaviour patterns such as queuing and overtaking. They do not consider the probabilities of vehicles avoiding the failure by swerving, or those of other vehicles colliding with the vehicle that collided with the block. However such detailed analyses would require rigorous traffic studies at each rock slope site on each route surveyed followed by complex probability analyses; this would be impractical. It is therefore considered that the above calculations provide a simple, best estimate of vehicle incident hazards that can be calculated from readily available data.

5.3.3.6 Calculation of Rating

The final calculation in deriving the rating value is to combine the Pv_{iday} and P_{vingt} values derived from the traffic calculations for each potential failure on the slope and to determine the probability that there will be a vehicle incident at the rock slope (P_{vi}).

P_{vi} values are likely to be very small in most cases and therefore difficult to visualise. A more user friendly set of values is therefore required for the Rating scale. Risk values are often quoted as a number of incidents per standard number of hours exposure. In particular the Fatal Accident Rate or FAR is quoted as the number of accidents per 100 million (10^8) hours of exposure (Kletz, 1992). Adopting a similar approach the Vehicle Incident Rate or VIR could be derived for each cutting and used as the Hazard Rating Value.

The VIR is calculated as follows:

If the probability of a vehicle incident at a cutting is P_{vi} and the number of vehicles passing that cutting per day is x the number of vehicle incidents N_{vi} at the cutting per day is given by:

$$N_{vi} = P_{vi}.X$$ Equation 14

The number of vehicle hours exposure N_{vh} at the cutting per day can be calculated as follows:

$$N_{vh} = x.S_1/V_s$$ Equation 15

Where

S_1 – Rock slope length)in miles)

V_s – Average vehicle speed (in mph)

x – Number of vehicles per carriageway per day for the road

There are therefore N_{vi} incidents at the cutting in N_{vh} hours of exposure. Converting this into similar units used for FAR to derive the VIR:

$$VIR = N_{vi}.10^8/N_{vh}$$ Equation 16

Substituting for N_{vi} from 14 above and N_{vh} from 15 above:-

$$VIR = P_{vi}.x.10^8/(x.S_1/V_8$$ Equation 17

$$VIR = P_{vi}.V_s.10^8/S_1$$ Equation 18

This should provide a satisfactory Hazard Rating value as it is likely to highlight those slopes with a high probability of vehicle incident per unit length of cutting.

It is likely that the final method of deriving the Rock Slope Hazard Rating from the probability of a vehicle incident at a cutting will require refinement once a number of field trials of the Rating have been completed. Trials of the Rating are also required to determine threshold levels for No Remedial Work, Remedial Work and Urgent Remedial Work action categories.

6 The Hazard Index Trial

6.1 Introduction

During development of the Rock Slope Hazard Index, in July 1994, SOID Roads Directorate, Network Management requested that a trial of the system be carried out on a section of trunk road. After consultation it was decided to carry out this trial on the A830 Fort William to Mallaig Trunk road in the Scottish highlands. A 50km section of the road between its junction with the A861 and Mallaig (Figure 15) was chosen as the trial site.

The objectives of the trial were to evaluate the new Hazard Index system, determine how this would fit into a rock slope hazard inventory and identify potentially hazardous slopes on the A830.

All of the slopes within the trial section of the A830 were surveyed by TRLS using the new Hazard Index system. Once this was complete a selected number of slopes were surveyed by experienced staff from two consultants to allow the repeatability and consistency of the Index results to be evaluated.

A full report on the TRL part of the trial has been submitted to SOID (PR/SC/17/94) and only the results and a brief summary of the work carried out are presented here.

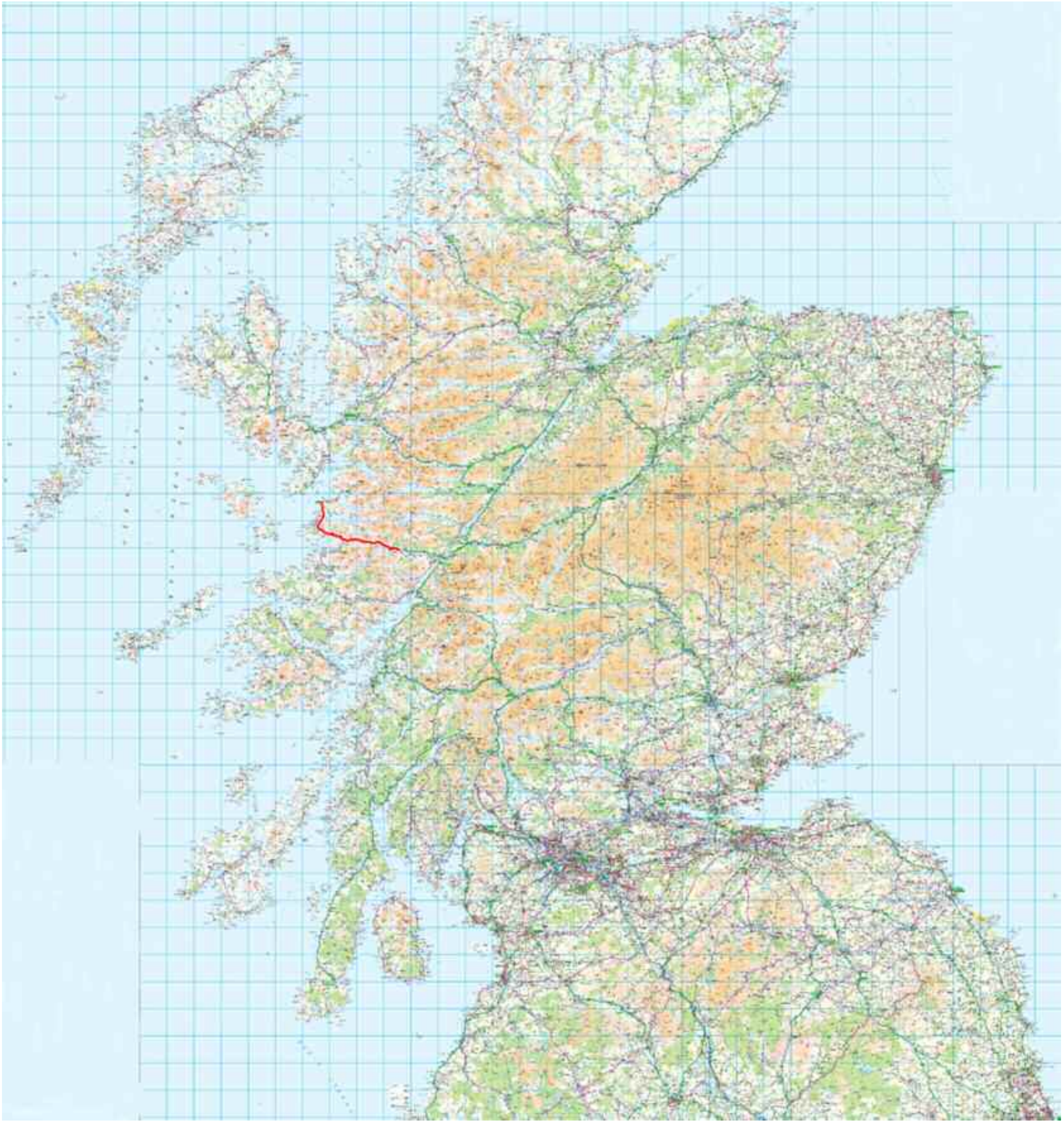

Figure 15. Location plan showing the length of the A830 used for the trial in red. (© Crown Copyright. All Rights Reserved Scottish Government 100020540, 2011.)

6.2 The TRL Trial and Results

Field work for the trial was carried out in two phases. The first, in July 1994, involved locating and photographing all of the rock slopes and recording geotechnical and geometric data in order to calculate the Rock Slope Hazard Indices. The second, in November 1994, involved carrying out an independent, subjective assessment of the rock slopes to act as a check for the Rock Slope Hazard Indices.

During the first phase of field work all of the rock slopes within the study area were referenced to the Network Link and Section markers and located on the 1:25000 scale maps. Photographs were taken of most rock slopes and many of these were taken as stereo pairs.

Topographic and geotechnical data were collected by a two man team using standard forms. It was possible to collect data from between 30 and 40 rock slopes in a day using this system.

The second phase of the field work involved making independent subjective hazard assessments for a randomly selected number (34) of rock slopes within the study area. The independent assessments were carried out by Dr G.D. Matheson who was not involved in either the first phase of the field work or calculating the Rock Slope Hazard Indices. The aim of this phase was to provide a reference against which the Rock Slope Hazard Index results could be compared.

Traffic data for the A830 were obtained from the Highland Region, Regional Traffic Flow Plan, 1993. The maximum seasonal flow values were used in deriving the Rock Slope Hazard Indices.

The field data were processed and analysed to derive a Rock Slope Hazard Index for each rock slope.

A total of 179 rock slopes were located and assessed on the A830 between the A861 junction and Mallaig. Rock Slope Hazard Indices for these slopes are shown in Appendix 7, Table A7.1 in order of slope number (numbered from West to East). Slope start and end network references and slope height category are also given in the tables.

Analysis of the results (Figure 16) reveals that 90 slopes (50.3%) require no further action, 64 slopes (35.8%) require a review inspection in 5 years, 22 slopes (12.3%) require a detailed inspection and 3 slopes (1.7%) require an urgent detailed inspection

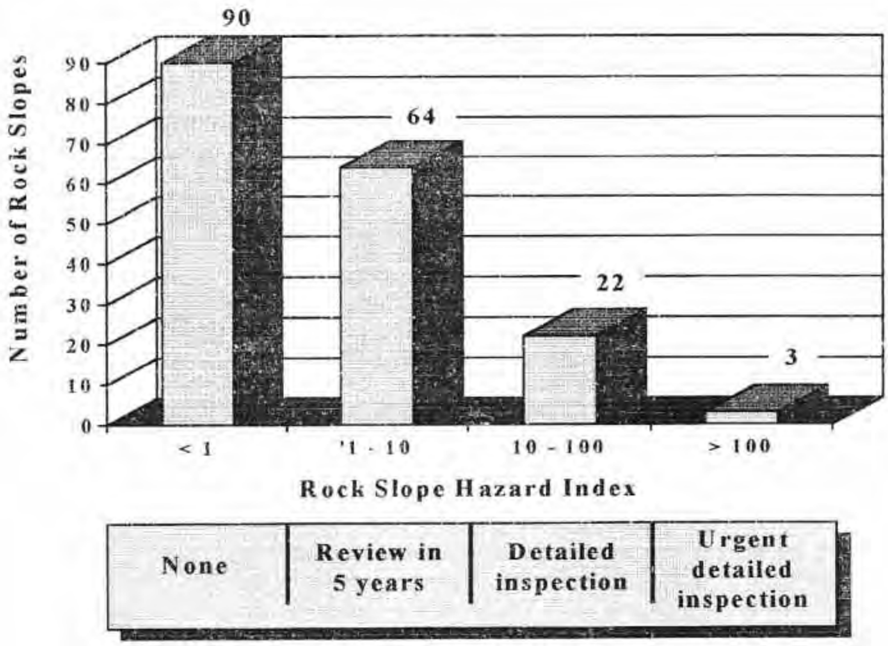

Figure 16. Distribution of Rock Slope Hazard Index values obtained from the TRL trial

Further analysis reveals a relationship between cutting height and action required (Figure 17). The data shows that as slopes get higher the percentage of slopes requiring no action decreases, the percentage requiring review shows a slight increase and the percentage requiring detailed inspection shows a marked increase. These trends cannot be reliably applied to slopes in the categories less than 2m and greater than 20m because of the small number slopes in each (1 and 5 respectively).

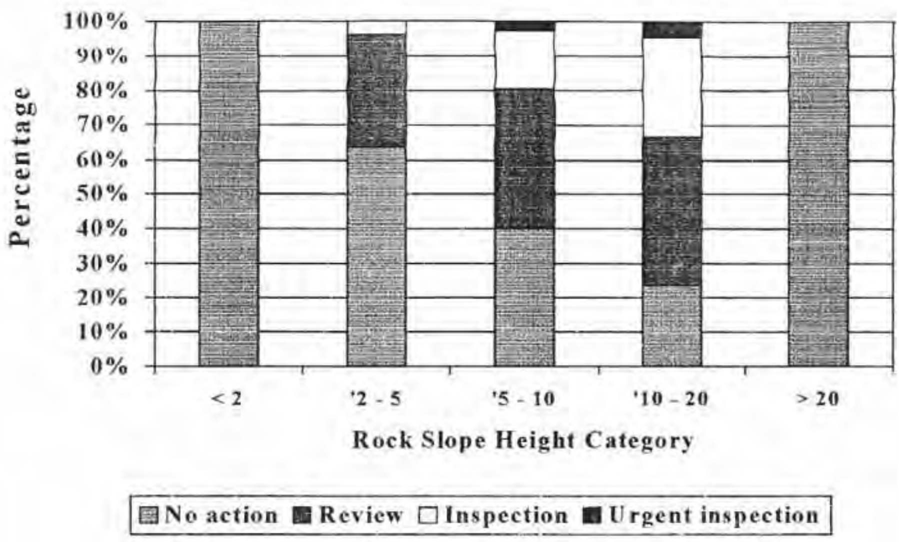

Figure 17. Variation in required action with slope height category

Comparison of action categories derived from the Rock Slope Hazard Index values with those derived from the subjective field assessment shows 79% agreement (Table 20). The discrepancies mainly occur between the no action and review categories (15%) with only 2 discrepancies (6%) between the review and detailed inspection categories in which the subjective assessment gave the higher category.

Table 20

Slope No.	Rock Slope Hazard Index Category	Subjective Category	Slope No.	Rock Slope Hazard Index Category	Subjective Category	Slope No.	Rock Slope Hazard Index Category	Subjective Category
6	1	1	69	1	1	125	2	2
15	1	1	70	1	1	127	1	1
25	2	2	71	4	4	137	2	2
28	1	1	72	1	1	140	1	1
32	2	1	73	4	4	142	2	2
41	1	1	74	3	3	144	2	2
42	2	1	75	4	4	147	2	1
43	3	3	80	3	3	159	1	2
46	3	3	98	1	1	169	1	1
48	3	3	101	2	1	172	2	3
53	3	3	106	2	3			
66	2	1	123	3	3			

The trial of the Rock Slope Hazard Index illustrated that the field work and follow up analysis could be carried out rapidly. In theory, so long as consistent results could be obtained, the Rock Slope Hazard Index could be applied as a management tool to allow priority based budgeting of rock slope maintenance. In order to evaluate the consistency of results obtained from the index two consultants were engaged to survey a number of the rock slopes on the A830.

6.3 Consultants Trial and Results

The consultants participating in the evaluation of the Rock Slope Hazard Index carried out their field work in February 1995. Consultant A surveyed a total of 80 rock slopes in 5 days and Consultant B surveyed a total of 63 rock slopes in 4 days. The field data sheets from both consultants were returned to TRLS for analysis and derivation of the Index.

The results obtained from the field work carried out by Consultant A and Consultant B are shown in Table 21. Figures 18 and 19 illustrate the number of slopes in each category obtained from the Consultants' field work.

Analysis of the results from Consultant A (Figure 18) reveals that 40 slopes (50%) require no further action, 20 slopes (25%) require a review inspection in 5 years, 12 slopes (15%) require a detailed inspection and 8 slopes (10%) require an urgent detailed inspection.

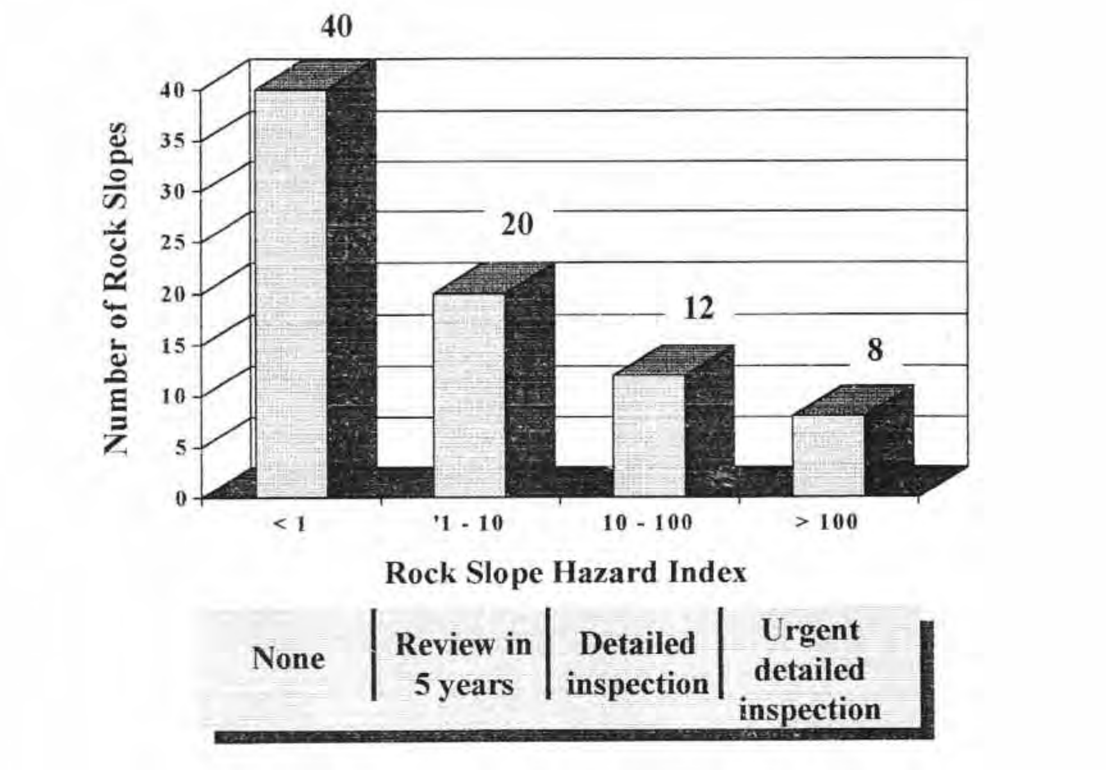

Figure 18. Summary of results from Consultant A.

Analysis of the results from Consultant B (Figure 19) reveals that 15 slopes (24%) require no further action, 19 slopes (30%) require a review inspection in 5 years, 22 slopes (35%) require a detailed inspection and 7 slopes (11%) require an urgent detailed inspection.

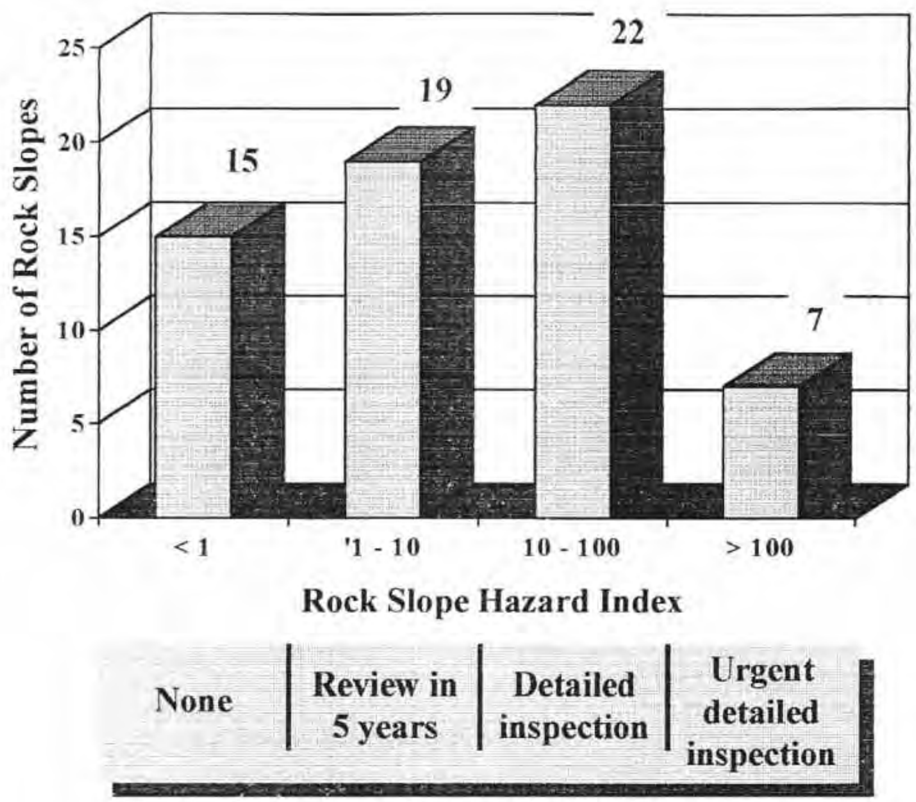

Figure 19 Summary of results from Consultant B.

6.4 Comparison and Discussion

The results obtained from Rock Slope Hazard Index surveys carried out by TRLS, Consultant A and Consultant B are given in Table 21. Comparison of Index values is less important than comparison of the action categories into which each of the slopes is placed by the Index results. The percentage of slopes in each action category for each set of results is shown in Figure 20.

Of the 80 slopes surveyed by Consultant A, 46 (58%) fall into the same action category as those obtained from the TRL survey. Of the remainder 15 were in a lower category and 19 were in a higher category than the results from the TRL survey. This is a poor comparison and indicates a poor level of consistency for the Index results.

A more detailed evaluation of the Consultant A data revealed that in general the reason for slopes falling into a lower action category was failure to recognise ravelling failure on rock slopes. The main reason for slopes falling into a higher action category was overestimation of discontinuity extent values. This problem is easy to recognise because in many cases extent values have been recorded that are physically impossible for the relevant slope.

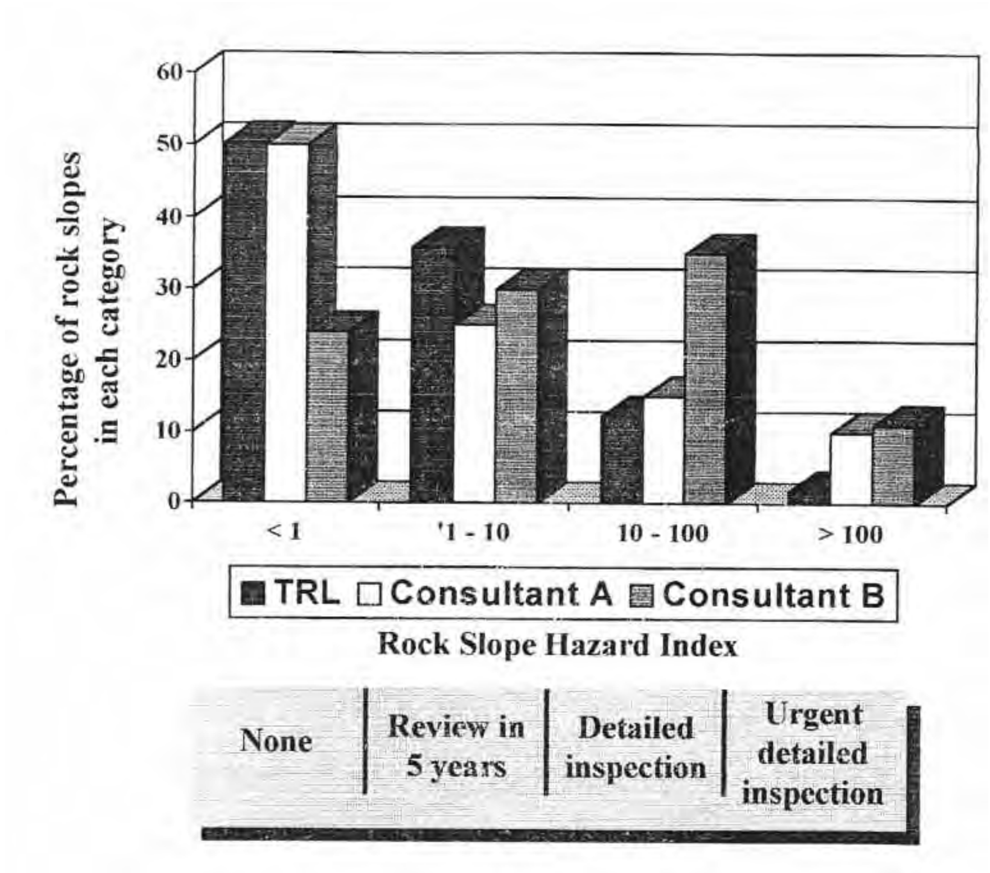

Figure 20. Comparison of results from TRL, Consultant A and Consultant B.

Of the 63 slopes surveyed by Consultant B 28 (44%) fall into the same action category as those obtained from the TRL survey. Of the remainder 6 were in a lower category and 29 were in a higher category than the results from the TRL survey. This is a poor comparison and indicates a poor level of consistency for the Index results.

A more detailed evaluation of the Consultant B data revealed that in general the reason for slopes falling into a lower action category were a failure to recognise potential failure and recording of the wrong slope angle category. The main reasons for slopes falling into a higher action category were underestimating verge and ditch sizes, overestimating the size of potential failures and overestimating discontinuity extent values.

Of the 42 slopes common to both the Consultant A and Consultant B surveys 17 (40%) fall into the same action category.

The main reasons for inconsistency in Index results would appear to be poor data collection practice and a lack of understanding of some terms on the data collection forms. Obviously if this were to continue on introduction of the Index as a standard system then it would create many problems. It will therefore be necessary to improve the standard and consistency of data collection. This could be done by either training on the Hazard Index and requiring that any users of the system must attended this training, or by issuing improved guidance notes to accompany the field data collection sheets. The latter of these solutions is likely to prove most acceptable.

Further trials preferably on the same slopes and using the same personnel should be conducted to assess the influence of improved guidance on data collection accuracy and consistency.

Other reasons for inconsistency in the Index results from the trial may relate to difficulties in locating and identifying rock slopes. Slope locations are referenced to the Trunk Road Link and Section numbers. However many of the marker posts between Link and Section end points are incorrectly located and were changed in the period between the TRL survey and the surveys by the Consultants. Both Consultants experienced difficulty in locating slopes and estimated that between 20 and 30 percent of time on site was used in trying to locate and confirm cuttings.

In processing of the results some of the slopes evaluated by the Consultants were found to be wrongly numbered and these were corrected. In general these numbering problems were identified from photographic records, however this was not always possible.

Permanently marking each slope should be considered to remove problems associated with identifying slopes for review and detailed inspections. The cost of this would be very rapidly recovered in the minimum 20% saving in survey time for review inspections.

Table 21

TRL Scotland			Consultant A		Consultant B	
Slope No.	Rock Slope Hazard Index	Action Category	Rock Slope Hazard Index	Action Category	Rock Slope Hazard Index	Action Category
1	0.175	1	0.07	1	-	-
4	0.017	1	0.01	1	0.063	1
5	0.145	1	-	-	0.267	1
7	0.01	1	0.04	1	0.438	1
8	1.585	2	0.063	1	4.586	2
10	0.209	1	0.16	1	-	-
12	0.002	1	0.065	1	-	-
14	0.003	1	0.003	1	-	-
17	0.004	1	0	1	47.851	3
18	0.479	1	0.002	1	-	-
19	11.936	3	1.851	2	12.088	3
20	0.004	1	-	-	0.046	1
22	0.313	1	0.664	1	-	-
24	8.813	2	0.486	1	-	-
26	0	1	0.1	1	77.429	3
28	0.007	1	0.665	1	-	-
29	0.009	1	3.092	2	-	-
30	8.852	2	1.996	2	-	-
32	5.346	2	-	-	10.613	3
34	7.24	2	4.079	2	2993.77	4
38	0.005	1	0	1	-	-
39	0.081	1	0.384	1	59.597	3
40	27.719	3	53.429	3	-	-
42	1.021	2	7.309	2	-	-
43	12.711	3	-	-	21.557	3
44	33.995	3	5.417	2	6.916	2
45	0.567	1	-	-	0.104	1
46	52.265	3	64.125	3	477.814	4
47	1.543	2	-	-	173.716	4
48	22.469	3	-	-	56.338	3

TRL Scotland			Consultant A		Consultant B	
Slope No.	Rock Slope Hazard Index	Action Category	Rock Slope Hazard Index	Action Category	Rock Slope Hazard Index	Action Category
50	0.173	1	0.054	1	0.113	1
53	47.644	3	83.222	3	157.288	4
55	2.921	2	5.732	2	1.421	2
57	0	1	0.227	1	1.251	2
58	46.163	3	2.456	2	7.236	2
59	0.003	1	0.017	1	-	-
60	3.479	2	11.128	3	-	-
61	3.642	2	16.004	3	7.425	2
62	6.776	2	0	1	-	-
63	5.810	2	1.308	2	-	-
66	5.625	2	4.616	2	6.819	2
68	0.789	1	0.004	1	0.406	1
71	171.128	4	95.583	3	54.037	3
72	0.936	1	0	1	12.996	3
73	621.264	4	602.227	4	8.945	2
74	10.66	3	-	-	19.816	3
75	276.485	4	249.603	4	3.358	2
76	11.95	3	133.482	4	14.122	3
81	3.558	2	3.822	2	-	-
82	7.052	2	1.285	2	3.265	2
84	0.002	1	0.001	1	0.008	1
85	0.371	1	-	-	219.441	4
88	0.009	1	0.008	1	-	-
89	0.009	1	0.0001	1	0.007	1
92	0.021	1	0.168	1	2.419	2
93	0.003	1	0.002	1	0.006	1
96	0.264	1	-	-	5.226	2
98	0.577	1	0.386	1	-	-
99	3.063	2	0.41	1	0.523	1
100	37.658	3	211.428	4	28.623	3
101	8.693	2	950.076	4	-	-
102	4.081	2	-	-	12.084	3
103	0.281	1	5.781	2	3.374	2
104	1.443	2	0.018	1	1.052	2
107	20.195	3	3048.947	4	236.132	4
109	0.661	1	-	-	3.672	2
111	2.123	2	22.299	3	-	-
112	0.660	1	4.391	2	0.149	1
113	1.129	2	27.831	3	8.721	2
115	30.054	3	2.393	2	0.113	1
116	0.007	1	-	-	8.189	2
118	0.511	1	65.239	3	-	-
120	4.977	2	39.109	3	70.64	3
122	5.620	2	-	-	8.819	2
124	4.138	2	31.486	3	-	-

TRL Scotland			Consultant A		Consultant B	
Slope No.	Rock Slope Hazard Index	Action Category	Rock Slope Hazard Index	Action Category	Rock Slope Hazard Index	Action Category
126	6.728	2	-	-	10.743	3
130	1.662	2	0.214	1	12.834	3
133	0.267	1	0.004	1	-	-
134	1.076	2	-	-	5.781	2
135	5.594	2	0.027	1	-	-
137	4.859	2	0.736	1	-	-
138	2A77	2	0	1	45.531	3
139	1.449	2	2.217	2	-	-
140	0.386	1	-	-	0.352	1
141	3.291	2	-	-	42.897	3
143	3.584	2	2.176	2	66.768	3
145	7.596	2	479.433	4	256.166	4
147	2.425	2	108.508	4	46.132	3
148	0.083	1	-	-	1.519	1
151	1.867	2	-	-	16.32	3
152	14.607	3	5.798	2	23.103	3
157	0.347	I	0.003	1	-	-
158	OA17	1	0.003	1	-	-
160	0.005	1	1.642	2	-	-
163	9.239	2	24.821	3	-	-
168	OA55	1	0.004	1	-	-
169	0.845	1	1.995	2	-	-
171	0.687	1	0.079	1	-	-
174	0.281	1	0.074	1	-	-
179	0	1	0.002	1	-	-
- Not surveyed						

7 Summary and Conclusions

Improved methods of identifying and classifying rock slope hazards are required to allow more effective management of the rock slopes on the Scottish Trunk Road Network. Existing methods employ variable approaches to data collection and use different scales and nomenclature for presentation of results rendering comparison of these results almost impossible.

A programme of research aimed at addressing the problem of the management of rock slopes was instigated by SOID Roads Directorate in 1993. The first stage of this research, Rock Slope Risk Assessment, is now complete and is the subject of this report.

The research reviewed risk assessment as applied to engineering geology and geotechnics and existing techniques of rock slope stability and hazard assessment. The advances in rock slope stability assessment and hazard identification made at TRL Scotland were also reviewed. This existing knowledge was distilled and combined with new thinking on the approach to stability and hazard assessment and resulted in development of a two stage approach to the assessment of rock slope hazard.

The first stage of the new approach derives a Rock Slope Hazard Index from rapid, standardised field data collection. This is based on standard forms, one for geotechnical parameters and the other for geometric parameters. The forms present a number of options for each parameter. Selection of the relevant options is based on visual assessment of the parameter in the field. Parameter values, that reflect the influence of parameters on rock slope hazard, are allocated to each parameter. A Hazard Index is then derived by following a standard calculation procedure and can be used to classify rock slopes into four categories:

Rock Slope Hazard Index Value	Action Category
< 1	1.No Action
1 -10	2. Review in Five Years
10 - 100	3. Detailed Inspection
> 100	4. Urgent Detailed Inspection

The second stage derives a Rock Slope Hazard Rating from data recovered from a detailed field survey. Only slopes with an Index of greater than 10 are subjected to these surveys. As with the Index, the field survey is standardised by using forms to aid data collection. There are five forms for the Rating, one each for potential plane, wedge, toppling and ravelling failure and one for a discontinuity survey and other general slope data. The Rating is derived from a semi-probabilistic analysis of these data. Analyses are then carried out for each potential failure on a rock slope and combined to give a probability that a vehicle incident will occur due to rock fall at the slope. A number of assumptions are made in deriving this probability. Some cannot be supported by historical precedent or rigorous research but are based on experience and expertise at TRLS. The probability of a vehicle incident is converted into a number of incidents in 108 vehicle hours of exposure to the rock fall hazard in order to make it compatible with other scales on which risk figures are quoted.

The Rock Slope Hazard Index is intended to act as a course sift. It identifies those slopes where the geotechnical and geometric conditions combine to give a potential for hazard to the road and road users and classifies these slope as requiring detailed or urgent detailed inspection. The Hazard Rating is intended to act as a fine sift. It identifies the level of hazard at each cutting surveyed allowing prioritisation of future maintenance commitments.

An extensive field trial of the Rock Slope Hazard Index was carried out on the A830 between Fort William and Mallaig. The results of this trial have demonstrated that the Index can provide a rapid method of deriving a representative assessment of the potential hazard at a rock slope. The results of the TRL survey were compared with the results of surveys carried out by two consultants. This demonstrated that the results of field assessments carried out by different people do not compare well. The variation in the results was found to be due to poor data collection practice, a lack of understanding of some of the terms used on the data forms and problems of identifying rock slopes on the part of the consultants.

It has not been possible to carry out trials of the Rock Slope Hazard Rating as part of this current research programme. It is likely that when such trials are conducted, some fine tuning of the Rating data collection and calculation procedures will occur.

Management of rock slope hazards on the Scottish Trunk Road Network could be significantly improved through application of the new approach to hazard assessment developed in this research. The Hazard Index provides a rapid, cost-effective means of identifying the number, location and severity of potentially hazardous slopes on the Network. The Index results allow effective use of inspection budgets through prioritisation. Wasteful detailed surveys of low or intermediate hazard rock slopes could be avoided.

8 Recommendations

Detailed trials of the Rock Slope Hazard Rating are required in order to evaluate its performance. These trials should be carried out on rock slopes already subjected to a Rock Slope Hazard Index survey, such as those on the A830 and the A82 Fort Augustus to Lochend.

The Rock Slope Hazard Index should continue to be used under close supervision. It is likely that during use in an increasing range of situations, the requirement for minor adjustments may become apparent.

Additional research should be conducted to investigate in more detail the influence of individual parameters on rock slope hazard. In many instances the parameter values used in deriving both the Index and Rating are based on subjective judgement and experience. Further investigation of these parameters is required to improve confidence in the parameter values and Index and Rating systems.

Detailed user guidance manuals should be compiled for both the Index and the Rating field surveys. Priority should be given to the Index as this system is in a more advanced state of development and application. The manual for the Index surveys would be required before any contracts could be let competitively.

For the time being it is suggested that Hazard Index surveys continue to be carried out by or under the supervision of, TRL Scotland. This will allow compilation of an extensive data base of Index values for a range of situations, provide the data for a better understanding of the behaviour of the index. Any anomalies in Index values would soon become apparent and the cause and cure investigated.

Implementation of the Rock Slope Hazard Index and Rating should be within the framework of the Maintenance Management Strategy for Rock Slopes that is currently under development as the second part of the Management of Rock Slopes research programme at TRLS.

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Appendix A Rock Slope Hazard Index: Field Data Collection Sheets

APPENDIX 1

Rock Slope Hazard Index

GEOTECHNICAL FIELD DATA COLLECTION SHEET

Cutting Ref.

Road Number   Nearest Town

Cutting Location

Start	G.R.		Network Ref.
Finish	G.R.		Network Ref.

1. Rock Strength

Weak   Mod. Str.   Strong   V. Strong

2. Rock Weathering

Fresh   Slight   Mod   Highly   Complete   Residual

3. Discontinuity Sets

< 3   3   4   > 4

4. Discontinuity Orientation

DIP

Set 1	Set 2	Set 3	Set 4	Set 5
< 30	< 30	< 30	< 30	< 30
30 - 45	30 - 45	30 - 45	30 - 45	30 - 45
45 - 70	45 - 70	45 - 70	45 - 70	45 - 70
70 - 90	70 - 90	70 - 90	70 - 90	70 - 90

AZIMUTH (relative to slope azimuth)

Set 1	Set 2	Set 3	Set 4	Set 5
within 20	within 20	within 20	within 20	within 20
20 - 90	20 - 90	20 - 90	20 - 90	20 - 90
> 90	> 90	> 90	> 90	> 90

5. Discontinuity Principle Spacing (Average for set)

Set 1	Set 2	Set 3	Set 4	Set 5
< 0.1m	< 0.1m	< 0.1m	< 0.1m	< 0.1m
0.1 - 0.3m	0.1 - 0.3m	0.1 - 0.3m	0.1 - 0.3m	0.1 - 0.3m
0.3 - 0.6m	0.3 - 0.6m	0.3 - 0.6m	0.3 - 0.6m	0.3 - 0.6m
0.6 - 2m	0.6 - 2m	0.6 - 2m	0.6 - 2m	0.6 - 2m
< 2m	< 2m	< 2m	< 2m	< 2m

6. Discontinuity Trace Length (Average for set)

Set 1	Set 2	Set 3	Set 4	Set 5
< 1m	< 1m	< 1m	< 1m	< 1m
1 - 3m	1 - 3m	1 - 3m	1 - 3m	1 - 3m
3 - 5m	3 - 5m	3 - 5m	3 - 5m	3 - 5m
5 - 10m	5 - 10m	5 - 10m	5 - 10m	5 - 10m
> 10m	> 10m	> 10m	> 10m	> 10m

Cutting Ref.

7. Discontinuity Dilation

Tight	< 2mm	2 - 5mm	> 5mm
Natural	Induced		

8. Potential Failure Observed on Slope

None	Plane	Wedge	Toppling	Ravelling
Position on slope	High	High	High	High
	Med	Med	Med	Med
	Low	Low	Low	Low

9. Sizes of Potential Failure Observed on Slope

Plane	Wedge	Toppling	Ravelling
< 0.5m3	< 0.5m3	< 0.5m3	< 0.1m3
0.5 - 1m3	0.5 - 1m3	0.5 - 1m3	0.1 - 0.5m3
1 - 3m3	1 - 3m3	1 - 3m3	0.5 - 1m3
> 3m3	> 3m3	> 3m3	> 1m3

10. Surface Water Flows

None Minor Major

11. Ground Water Seepages

None Minor Major

12. Verge Materials

Rock Hard Gravel Topsoil Soft Vege.

13. Associated Hazards

Steep Down Slope Opposite Cutting	Residence / Buildings Above Cutting
Loch Opposite Cutting	Road / Access Above Cutting
Residence / Buildings Opposite Cutting	Services Above Cutting

Logged By	Date
Input By	Date
Checked By	Date

COMMENTS

Rock Slope Hazard Index

GEOMETRIC FIELD DATA COLLECTION SHEET

Cutting Ref.

Road Number | Nearest Town

Cutting Location

Start	G.R.		Network Ref.
Finish	G.R.		Network Ref.

1. Cutting Slope Height

< 2m | 2 - 5m | 5 -10m | 10 - 20m | >20m

2. Cutting Slope Angle

< 45 | 45 - 60 | 60 - 70 | 70 - 90

3. Angle of Natural Slope Above Cutting

< 20 | 20 - 30 | 30 - 45 | 45 - 60 | > 60

4. Rock Slope Profile

Even (relief < 1m) | Rough (relief 1 - 2m) | V. rough (relief >2m)

5. Berms

None | < 2m wide | 2 - 4m wide | > 4m wide

6. Verge Width

< 0.5m | 0.5 - 1m | 1 - 2m | 2 - 4m | 4 - 6m | > 6m

7. Ditch Width

None | < 0.5m | 0.5 - 1m | 1 - 2m | 2 - 4m | > 4m

8. Ditch Depth

None | < 0.5m | 0.5 - 1m | > 1m

9. Distance to Fence

None | < 0.5m | 0.5 - 1m | 1 - 2m | 2 - 4m | > 4m

10. Fence Height

None | < 0.5m | 0.5 - 1m | > 1m

11. Carriageway Width

< 6m | 6 - 8m | 8 - 10m | > 10m

12. Sight Lines

< 40m | 40 - 60m | 60 - 100m | >100m

13. Cutting Type

Side-long | Box

TRL

Cutting Ref.

14. Associated Hazards

Steep Down Slope Opposite Cutting

Loch Opposite Cutting

Residence / Buildings Opposite Cutting

Residence / Buildings Above Cutting

Road / Access Above Cutting

Services Above Cutting

Sketch

Photos

Full Cover Part Cover Stereo

Comments

Logged By Date

Input By Date

Checked By Date

Rock Slope Hazard Index

EXISTING REMEDIAL WORK FIELD DATA COLLECTION SHEET

Cutting Ref.

Road Number

Nearest Town

Cutting Location

Start	G.R.		Network Ref.
Finish	G.R.		Network Ref.

1. Rock Removal

Scaling	Controlled Removal	Reprofile
Light	Explosive	
Heavy	Non-Explosive	
% Area	% Area	% Area
Dates	Dates	Date

2. Rock Containment

Netting	Ditches	Barriers
Draped		Rigid
Contoured		Flexible
Fixed		Bunds
% Area	% Length	% Length
Dates	Dates	Date

3. Rock Strengthening

Rock Reinforcement

Anchors	Bolts	Dowels
Mono Bar		
Multistrand		
Numbers		
< 5	< 5	< 5
5 - 10	5 - 10	5 - 10
>10	>10	>10
% Area	% Area	% Area
Dates	Dates	Date

Support

Retaining Wall	Buttress	Sprayed concrete	Waling	Strapping
% Area	% Area	% Area	% Area	% Area
Dates	Dates	Dates	Dates	Dates

Protection

Sprayed concrete	Dentition
% Area	% Area
Dates	Dates

Cutting Ref.

4. Total % Hazards Treated

Rem. Act					
Plane	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%
Wedge	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%
Toppling	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%
Ravelling	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%

5. Effectiveness of Remedial Works

Rem. Act					
Plane	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%
Wedge	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%
Toppling	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%
Ravelling	< 25%	25 - 50%	51 - 75%	75 - 90%	> 90%

Comments

Logged By Date

Input By Date

Checked By Date

Appendix B Rock Slope Hazard Index: Parameter Library

B.1 Geotechnical Parameters

Initial Parameter Indices Derived From Discontinuity - Slope Geometry Relationships

Plane Failure

Criteria - Plane must dip > 30 degrees (assumed nominal friction value) at an azm of slope azm + or - 20 degrees and plane dip < slope dip

Plane Orientations Dip	Azm	Slope Orientations Dip	Initial Parameter	FOS Parameter
30 - 45	*+/-20*	<45	**0.5**	**1.3**
30 - 45	*+/-20*	45 - 60	**1**	**1.3**
30 - 45	*+/-20*	60 - 70	**1**	**1.3**
30 - 45	*+/-20*	70 - 90	**1**	**1.3**
45 - 70	+/-20	<45	**0**	**2.7**
45 - 70	+/-20	45 - 60	**0.3**	**2.7**
45 - 70	+/-20	60 - 70	**0.8**	**2.7**
45 - 70	+/-20	70 - 90	**1**	**2.7**
70 - 90	+/-20	<45	**0**	**10.24**
70 - 90	+/-20	45 - 60	**0**	**10.24**
70 - 90	+/-20	60 - 70	**0**	**10.24**
70 - 90	*+/-20*	70 - 90	**0.5**	**10.24**

Wedge Failure

Criteria – Intersection must be formed from planes from separate sets. Intersection must dip > 30 degrees and daylight on slope.

Wedge Plane Orientations

Set1 Dip	Azm	Set2 Dip	Azm	Slope Orientations Dip	Initial Parameter	FOS Parameter
30 - 45	+20 - 90	30 -45	- 20 -90	<45	0.09	0.67
30 - 45	+ 20 - 90	30 - 45	- 20 -90	45 - 60	0.16	0.67
30 - 45	+ 20 - 90	30 - 45	- 20 - 90	60 - 70	0.16	0.67
30 - 45	+ 20 - 90	30 - 45	- 20 -90	70 - 90	0.16	0.67
30 - 45	+20 - 90	45 -70	- 20 - 90	<45	0.18	0.82
30 - 45	+20 - 90	45 -70	- 20 -90	45 - 60	0.37	0.82
30 - 45	+20 - 90	45 -70	- 20 - 90	60 - 70	0.37	0.82
30 - 45	+20··90	45 -70	- 20 -90	70 - 90	0.37	0.82
30 - 45	+20 - 90	70··90	- 20 -90	<45	0.25	0.96
30 - 45	+20 - 90	70 - 90	- 20 -90	45 - 60	0.5	0.96
30 - 45	+20 - 90	70 - 90	- 20 - 90	60 - 70	0.5	0.96
30 - 45	+20 - 90	70 - 90	- 20 -90	70 - 90	0.5	0.96
45 - 70	+ 20 - 90	45 -70	- 20 - 90	<45	0.15	1.12
45 . 70	+20 - 90	45 - 70	- 20 -90	45 - 60	0.45	1.12
45 - 70	+ 20 - 90	45 -70	- 20 -90	60 - 70	0.67	1.12
45 - 70	+ 20 - 90	45 -70	- 20 - 90	70 - 90	0.77	1.12
45 -70	+20 - 90	70-90	- 20 -90	<45	0.16	1.55
45 -70	+20 - 90	70 - 90	- 20 -90	45 - 60	0.49	1.55
45 -70	+20 - 90	70 - 90	- 20 - 90	60 - 70	0.75	1.55
45 -70	+20 - 90	70 - 90	- 20 - 90	70 - 90	0.86	1.55
70 - 90	+ 20 - 90	70 - 90	- 20 - 90	<45	0.12	3.13
70 - 90	+ 20 - 90	70 - 90	- 20 - 90	45 - 60	0.36	3.13
70 - 90	+20 - 90	70 - 90	- 20 - 90	60 - 70	0.57	3.13
70 - 90	+ 20 - 90	70 - 90	- 20 -90	70 - 90	0.81	3.13

Toppling Failure Index

Criteria - Intersection must dip > 60 toward (slope azm + *180)* + / - 20 and plane must dip < 30 toward slope Azm +/- *20*

Toppling Plane Orientations

Set1		Set2		Set 3		**Initial Parameter**
Dip	Azrn	Dip	Azrn	Dip	Azm	
30 - 45	+ 20 - 90	30 - 45	- 20 - 90	<30	+ / - 20	**0**
30 -45	+20 - 90	30 - 45	>90	<30	+ / - 20	**0**
30 - 45	>90	30 - 45	>90	<30	+ / - 20	**0**
30 - 45	+ 20 - 90	45 -70	- 20 - 90	<30	+ / - 20	**0**
30 -45	+ 20 - 90	*45 -70*	*>90*	*<30*	+ / - 20	**0**
30 - 45	>90	45 -70	- 20 - 90	*<30*	+ / - 20	**0**
30 -45	>90	45 -70	>90	<30	+ / - 20	**0**
30 - 45	+ 20 - 90	70 - 90	- 20 - 90	<30	+ / - 20	**0**
30 -45	+ 20 - 90	70 - 90	>90	<30	+ / - 20	**0**
30 - 45	>90	70 - 90	- 20 - 90	<30	+ / - 20	**0**
30 - 45	>90	70 - 90	>90	<30	+ / - 20	**0**
45 -70	+20 - 90	45 -70	- 20 - 90	<30	+ / - 20	**0**
45 -70	+ 20 - 90	45 -70	>90	<30	+ / - 20	**0**
45,·70	>90	45 -70	>90	<30	+ / - 20	**0.06**
45 -70	+ 20 - 90	70 - 90	- 20 - 90	<30	+ / - 20	**0**
45 -70	+20 - 90	70 - 90	> 90	<30	+ / - 20	**0**
45 -70	>90	70 - 90	- 20 - 90	<30	+ / - 20	**0.12**
45 -70	>90	70 - 90	>90	<30	+ / - 20	**0.24**
70 - 90	+ 20 - 90	70 - 90	- 20 - 90	<30	+ / - 20	**0.04**
70 - 90	>90	70-90	- 20 - 90	<30	+ / - 20	**0.27**
70 - 90	>90	70 - 90	>90	<30	+ / - 20	**0.77**

Discontinuity Size and Spacing Factors

Indices for each type of failure are multiplied by the principle spacing factors and persistence factors for each relevant joint set

Principle Spacing Factor

Range	Parameter Value	Type
<0.1 m	9	Multiplicative
0.1 – 0.3m	2.25	Multiplicative
0.3 – 0.6m	1	Multiplicative
0.6 – 2m	0.35	Multiplicative
>2m	0.11	Multiplicative

Persistence Factor

Range	Parameter Value	Type
1 m	0.25	Multiplicative
1 - 3m	1	Multiplicative
3 – 5m	4	Multiplicative
5 – 10m	14	Multiplicative
>10m	56	Multiplicative

Dilation Factor

Range	Parameter Value	Type
tight	1	Multiplicative
<2mm	1.2	Multiplicative
2 – 5mm	1.3	Multiplicative
>5mm	1.4	Multiplicative

Factors for Observed Failure Conditions on Slope

Multiplicative parameters

Parameter		Parameter value		Parameter value	
Plane Failure	Observed	1	Not Observed	0.5	Multiplicative
Wedge Failure	Observed	1	Not Observed	0.5	Multiplicative
Toppling Failure	Observed	2	Not Observed	0.5	Multiplicative

Factors for Observed Failure Conditions on Slope (cont.)

Additive parameters

Parameter	Parameter Value	Type
Plane Failure	**1**	Initial
Wedge Failure	**1**	Initial
Toppling Failure	**2**	Initial
Ravelling	**2**	Initial

Position Factor

Parameter	Parameter Value	Type
High on Slope	**1.2**	Multiplicative
Med on Slope	**1**	Multiplicative
Low on Slope	**0.8**	Multiplicative

Size Factor

Plane Wedge and Toppling

Parameter	Parameter Value	Type
$<0.5m^3$	**1**	Multiplicative
$0.5 – 1m^3$	**1.5**	Multiplicative
$1 – 3m^3$	**4**	Multiplicative
$>3m^3$	**9**	Multiplicative

Ravelling

Parameter	Parameter Value	Type
$<0.1m^3$	**1**	Multiplicative
$0.1 – 0.5m^3$	**1.2**	Multiplicative
$0.5 – 1m^3$	**4.5**	Multiplicative
$>1m^3$	**9**	Multiplicative

Weathering Strength and Water Factors

Weathering Factor

Option	Parameter Value	Type
Fresh	**1**	Multiplicative
slight	**1**	Multiplicative
moderate	**1.2**	Multiplicative
highly	**1.5**	Multiplicative
complete	**2**	Multiplicative
residual	**2.5**	Multiplicative

Strength Factor

Parameter	Parameter Value	Type
weak	**2**	Multiplicative
mod. str	**1.5**	Multiplicative
strong	**1**	Multiplicative
v.strong	**1**	Multiplicative

Ground Water Factor

Parameter	Parameter Value	Type
none	**1**	Multiplicative
minor	**1.1**	Multiplicative
major	**1.2**	Multiplicative

Rock Slope Hazard Index Parameter Library

B.2 – Geometric Parameters

Natural Slope Angle Factor

Parameter	**Parameter Value**	Type
<20	0	Additive
20 - 30	**0.5**	Additive
30 - 45	1	Additive
45 - 60	**1.5**	Additive

Rock Trap - Slope Height, Angle Factor and Rock Trap Failure size Factor

Rock Trap Parameters for Block Fall - Slope Height, Angle Factor - applies to block failure mechanisms ie up to 0.5 m3

Note derived with reference to Ritchie and Mak and Blomfield

Slope Height		<2m	2 - 5m				5 - 10m				10 -20m				>20m			
Slope angle		any	30 - 45	45 - 60	60 -70	70 - 90	30 - 45	45 - 60	60 -70	70 - 90	30 - 45	45 - 60	60 -70	70 - 90	30 - 45	45 - 60	60 - 70	70 - 90
Trap w	d	Value	**Parameter Values**				**Parameter Values**				**Parameter Values**				**Parameter Values**			
0	0	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	0	0.8	**1**	**1**	**0.95**	**0.9**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
0.5	0.5	0.1	**0.4**	**0.6**	**0.5**	**0.4**	**0.65**	**0.75**	**0.8**	**0.8**	**0.8**	**0.9**	**0.95**	**0.95**	**0.8**	**0.95**	**0.95**	**0.95**
1	0	0.3	**0.6**	**0.75**	**0.7**	**0.55**	**0.9**	**0.95**	**0.9**	**0.8**	**0.95**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
1	0.5	0.001	**0.05**	**0.1**	**0.1**	**0.05**	**0.4**	**0.5**	**0.5**	**0.4**	**0.5**	**0.7**	**0.7**	**0.6**	**0.6**	**0.8**	**0.9**	**0.8**
1	1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.15**	**0.15**	**0.1**	**0.15**	**0.35**	**0.35**	**0.2**	**0.3**	**0.6**	**0.7**	**0.4**
1	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.05**	**0.001**	**0.2**	**0.2**	**0.1**	**0.1**	**0.3**	**0.3**	**0.2**
2	0	0.001	**0.1**	**0.15**	**0.15**	**0.1**	**0.4**	**0.5**	**0.5**	**0.35**	**0.55**	**0.75**	**0.75**	**0.6**	**0.5**	**0.95**	**0.95**	**0.6**
2	0.5	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.1**	**0.2**	**0.2**	**0.1**	**0.15**	**0.35**	**0.35**	**0.15**	**0.4**	**0.7**	**0.7**	**0.4**
2	1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.05**	**0.01**	**0.001**	**0.1**	**0.1**	**0.05**	**0.1**	**0.2**	**0.2**	**0.1**
2	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.05**	**0.001**	**0.001**	**0.05**	**0.05**	**0.01**
4	0	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.1**	**0.25**	**0.25**	**0.15**	**0.2**	**0.3**	**0.3**	**0.2**	**0.3**	**0.5**	**0.5**	**0.3**
4	0.5	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.05**	**0.001**	**0.001**	**0.1**	**0.1**	**0.05**	**0.05**	**0.15**	**0.15**	**0.05**
4	1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.05**	**0.001**	**0.001**	**0.01**	**0.01**	**0.001**
4	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
6	0	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.05**	**0.01**	**0.01**	**0.15**	**0.1**	**0.01**	**0.15**	**0.35**	**0.35**	**0.1**
6	0.5	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.05**	**0.01**
6	1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
6	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
>6	0	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.01**	**0.001**	**0.05**	**0.05**	**0.01**	**0.01**
>6	0.5	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
>6	1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
>6	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Note all values multiplicative

Rock Trap Parameters for Failure volumes

Derivation of Trap / failure size Factors. For failure masses in which the failed mass forms a half cone spoil at the toe of the slope
where height of half cone = radius for 2 - 5m slopes, 2/3 radius for 5 c 10m slopes, 1/2 radius for 10 - 20m slopes and 1/3 radius for> 20m slopes.
If trap is almost totally effective for given slope height/angle combination then value = 0.001 if not then estimated percentage effectiveness given
Percentage estimates related to existing published data.

Slope Height		<2m	2-5m				5 - 10m				10 - 20m				>20m			
Failure Volume			0.5	1	3	6	0.5	1	3	6	0.5	1	3	6	0.5	1	3	6
Radius		any	0.97721	1.38198	2.39365	3.38514	1.19683	1.69257	2.93162	4.14593	1.38198	1.95441	3.38514	4.78731	1.69257	2.39365	4.14593	5.86323
Trap		Values	**Parameter Values**				**Parameter Values**				**Parameter Values**				**Parameter Values**			
w	d																	
0	0	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
0.5	0	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
0.5	0.5	0.1	**0.6**	**0.8**	**1**	**1**	**0.7**	**0.95**	**1**	**1**	**0.9**	**1**	**1**	**1**	**0.95**	**1**	**1**	**1**
1	0	0.3	**0.7**	**1**	**1**	**1**	**0.95**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
1	0.5	0.001	**0.1**	**0.4**	**0.7**	**1**	**0.35**	**0.6**	**0.9**	**1**	**0.7**	**0.9**	**1**	**1**	**0.8**	**0.95**	**1**	**1**
1	1	0.001	**0.001**	**0.001**	**0.0]**	**0.25**	**0.1**	**0.2**	**0.5**	**0.7**	**0.3**	**0.5**	**0.8**	**1**	**0.6**	**0.75**	**1**	**1**
1	>1	0.001	**0.001**	**0.001**	**0.001**	**0.05**	**0.05**	**0.1**	**0.2**	**0.4**	**0.1**	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**1**	**1**
2	0	0.001	**0.15**	**0.4**	**1**	**1**	**0.5**	**0.7**	**1**	**1**	**0.6**	**1**	**1**	**1**	**0.95**	**1**	**1**	**1**
2	0.5	0.001	**0.01**	**0.05**	**0.1**	**0.3**	**0.2**	**0.3**	**0.5**	**0.8**	**0.3**	**0.5**	**0.7**	**0.9**	**0.7**	**0.85**	**0.95**	**1**
2	1	0.001	**0.001**	**0.001**	**0.01**	**0.15**	**0.05**	**0.1**	**0.2**	**0.4**	**0.05**	**0.2**	**0.3**	**0.55**	**0.2**	**0.5**	**0.6**	**0.8**
2	>1	0.001	**0.001**	**0.001**	**0.001**	**0.1**	**0.001**	**0.01**	**0.05**	**0.1**	**0.001**	**0.01**	**0.1**	**0.25**	**0.1**	**0.2**	**0.35**	**0.5**
4	0	0.001	**0.001**	**0.01**	**0.05**	**0.2**	**0.2**	**0.3**	**0.6**	**1**	**0.3**	**0.4**	**0.6**	**1**	**0.5**	**0.7**	**1**	**1**
4	0.5	0.001	**0.001**	**0.001**	**0.01**	**0.1**	**0.01**	**0.05**	**0.15**	**0.3**	**0.05**	**0.15**	**0.3**	**0.5**	**0.1**	**0.25**	**0.6**	**0.75**
4	1	0.001	**0.001**	**0.001**	**0.001**	**0.01**	**0.001**	**0.01**	**0.05**	**0.1**	**0.001**	**0.05**	**0.1**	**0.3**	**0.05**	**0.15**	**0.3**	**0.5**
4	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.1**	**0.001**	**0.05**	**0.1**	**0.2**
6	0	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.1**	**0.15**	**0.3**	**0.15**	**0.2**	**0.4**	**0.7**	**0.3**	**0.5**	**0.6**	**0.9**
6	0.5	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.001**	**0.01**	**0.1**	**0.3**	**0.05**	**0.1**	**0.2**	**0.4**
6	1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.1**	**0.001**	**0.01**	**0.1**	**0.2**
6	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.1**
>6	0	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.05**	**0.1**	**0.2**	**0.4**	**0.05**	**0.15**	**0.3**	**0.5**
>6	0.5	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.1**	**0.001**	**0.05**	**0.1**	**0.25**
>6	1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.001**	**0.01**	**0.05**	**0.1**
>6	>1	0.001	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Note all values multiplicative

Slope Profile Factors

Profile factor

Option	Parameter Values	Type
Even	**1**	Multiplicative
Rough	**1.1**	Multiplicative
v. rough	**1.2**	Multiplicative

Berm factor

Option	Parameter Values	Type
None	**1**	Multiplicative
<2m	**1.2**	Multiplicative
2 – 4m	**1**	Multiplicative
>4m	**0.8**	Multiplicative

Road Geometry Factors

Carriageway Width Factor

Option	Parameter Values	Type
<6m	**1.2**	Multiplicative
6 – 8m	**1**	Multiplicative
8 – 10m	**0.9**	Multiplicative
>10m	**0.7**	Multiplicative

Sight Lines Factor

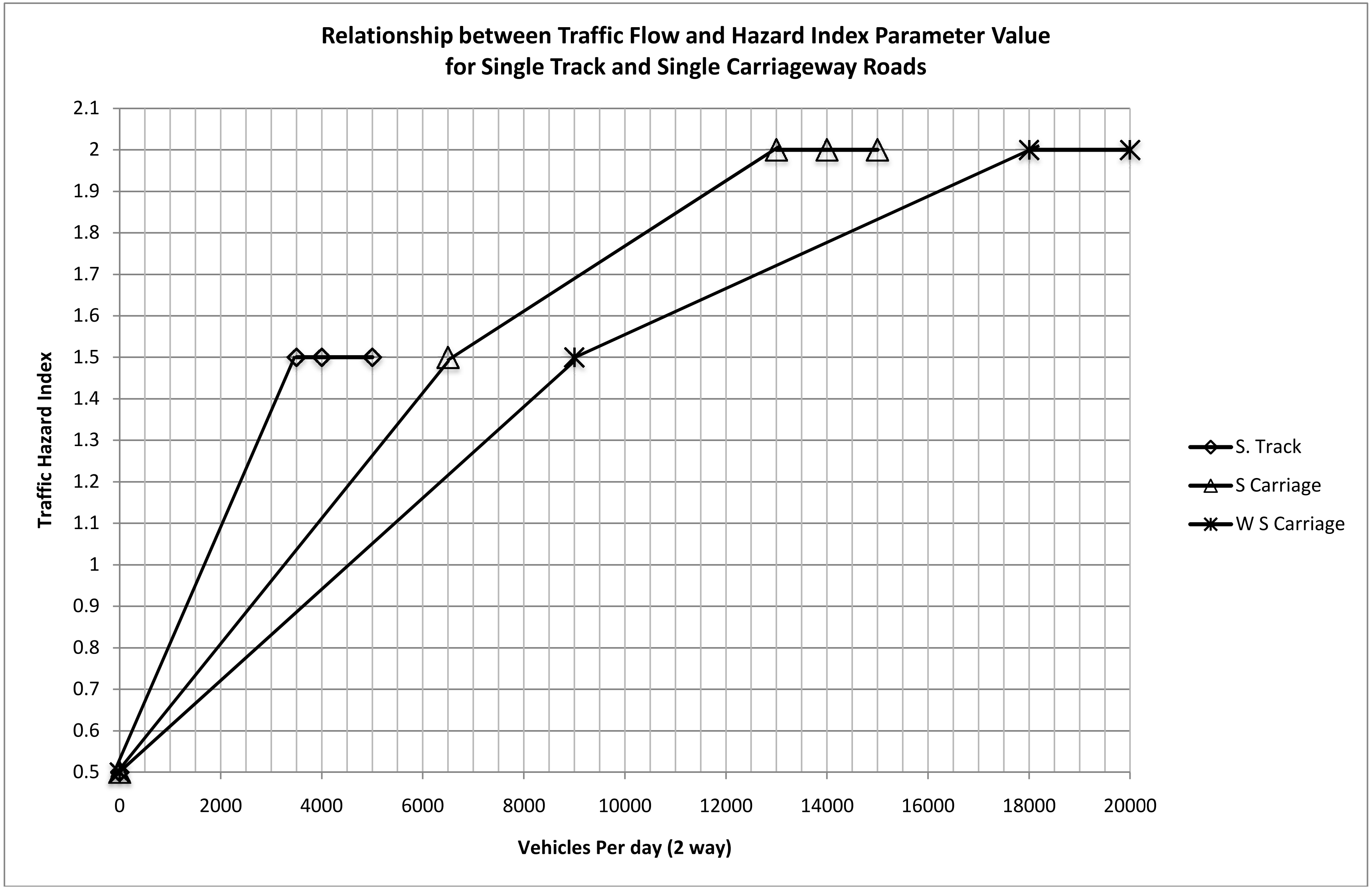
Option	Parameter Values	Type
<40m	**1.5**	Multiplicative
40 – 60m	**1**	Multiplicative
60– 100m	**0.8**	Multiplicative
>100m	**0.7**	Multiplicative

Cutting Type Factor

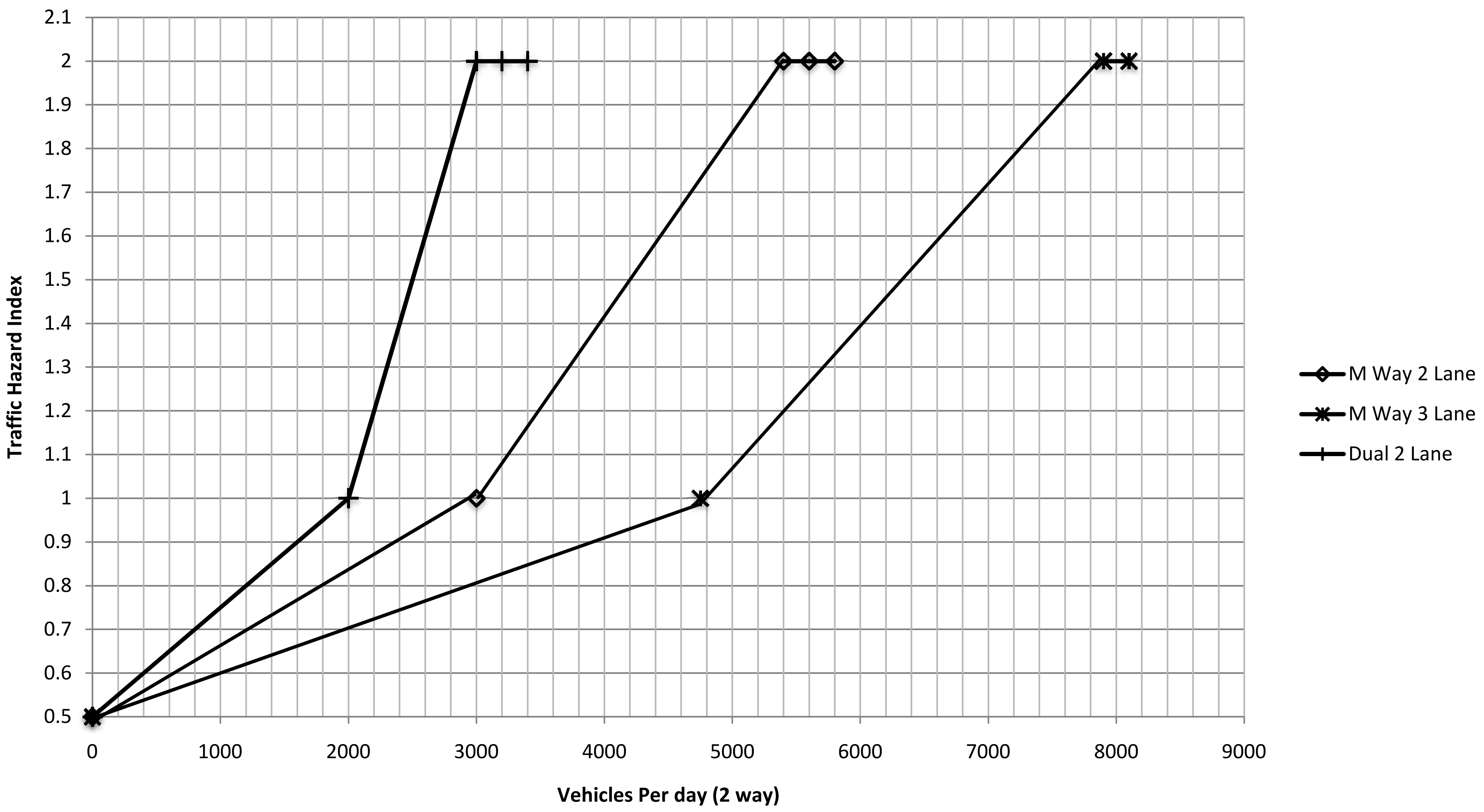
Option	Parameter Values	Type
Side-long	**1**	Multiplicative
Box	**1.05**	Multiplicative

Associated Hazards

Option	**Parameter Values**	Type
Steep Down-slope Opposite	**1.05**	Multiplicative
Loch Opposite	**1.05**	Multiplicative
Buildings Opposite	**1.05**	Multiplicative
Buildings Above	**1.05**	Multiplicative
Road Above	**1.01**	Multiplicative
Services Above	**1.01**	Multiplicative


Relationship between Traffic Flow and Hazard Index Parameter Value
for Single Track and Single Carriageway Roads
Traffic Hazard Index
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Vehicles Per day (2 way)
S. Track
S Carriage
W S Carriage

Relationship Between Traffic Flow and Hazard Index Parameter Value for Dual Carriageways and Motorways



Appendix C Rock Slope Hazard Index: Worked Examples

To illustrate the process of deriving the Rock Slope Hazard Index two examples are presented in tables A3.l and A3.2. The case is slope with relatively simple geotechnical conditions and the second is a more complex rock slope.

Table CASE 1. Trial Rock Slope No. 46

Field Data	**Hazard Index Parameter**	**Parameter Value**
Discontinuities: - Set 1: Dip 70 - 90 Azm + or - 20 Set 2: Dip 70 - 90 Azm - 20 - 90 Set 3: Dip < 30 Azm >90 Slope Angle: Dip 70 - 90	Initial Parameter Index; Plane failure criteria satisfied Set 1 > 30 and < slope angle Factor of Safety Parameter; Plane failure on Set 1	 0.5 10.24
Discontinuity Principle Spacing Set 1: 0.3 - 0.6m	Principle Spacing Factor for Set 1	1
Discontinuity Persistence Set 1: 5 - 10m	Persistence Factor for Set 1	14
Failure Observed - Yes	Failure Observation Parameter	1
	Part 1 Index	0.5*10.24*1*14*1 = **86.016**
Type of Failure Observed on Slope Plane	Failure Observation Parameter	1
Position of Failure - High	Failure position factor	1.2
Failure Size - > $3m^3$	Failure Size Factor	9
	Part 2 Index	1*1.2*9 = **10.8**
Rock Weathering; - Slight	Weathering parameter	1
Rock Strength - V. Strong	Strength Parameter	1
Ground Water - None	Ground Water Parameter	1
Natural Slope Above Cutting - 20 - 30	Natural Slope Parameter	0.5
Slope Height - 10 - 20m Slope Angle - 70 - 90 Verge Width - 2 - 4m Ditch Width - 1 - 2rn Ditch Depth - < 0.5m Distance to Fence - None	Rock Trap Parameter Case 1 2 - 4m wide 0m deep Case 2 1 - 2m wide < 0.5m deep Lowest Used	 1 0.6 0.6
Slope Profile - V. Rough	Slope Profile Parameter	1.2
Berms - None	Berm Parameter	1
Carriageway Width - < 6m	Carriageway Width Parameter	1.2
Sight Lines - 60 – l00m	Sight Lines Parameter	0.8
Cutting; Type - Side Long	Cutting; Type Parameter	1
Associated Hazards Loch Opposite Cutting	Associated Hazards Parameter	1.05
Road Category - S2 Traffic Volume - 1555 vpd	Traffic Parameter	0.74

Table (Cont.) CASE 1, Trial Rock Slope No. 46

Calculation of the Rock Slope Hazard Index
Part 1 index + part 2 index = 86.016 + 10.8 = 96.816

Take into account weathering, strength and ground water for each failure type.
96.816 * 1 (weathering) * 1 (strength) * 1(ground water) = 96.816

Take into account the possibility of failures on any natural slope above cutting.
96.816 + 0.5 (natural slope) = 97.316

Take into account rock trap, slope profile, berms, carriageway width, sight lines, cutting type, associated hazards and traffic factors.
97.316 * 0.6 (rock trap) * 1.2 (profile) * 1 (berm) * 1.2 (carriageway) * 0.8 (sight lines) * 1 (cutting type) * 1.05 (associated hazards) * 0.74 (traffic parameter) = 52.26

Rock Slope Hazard Index = 52.26

Table CASE 2, Trial Rock Slope No. 73

Field Data	Hazard Index Parameter	Parameter Value
Discontinuities:- Set 1: Dip 70 - 90 Azm + or - 20 Set 2: Dip 70 - 90 Azm - 20 - 90 Set 3: Dip 70 - 90 Azm - > 90 Set 4: Dip 30 - 45 Azm > 90 Set 5: Dip 70 - 90 Azm - 20 - 90 Slope Angle: Dip 70 - 90	Initial Parameter Index; Plane failure criteria satisfied Set 1 > 30 and < slope angle Factor of Safety Parameter; Plane failure on Set 1 Wedge failure criteria satisfied set 2 + set 5 Factor of Safety Parameter; Wedge failure on Set 2 and set 5	 0.5 10.24 0.81 3.13
Discontinuity Principle Spacing Set 1: 0.3 - 0.6m Set 2: 0.1 - 0.3m Set 5: 0.1 - 0.3m	Principle Spacing Factor for Set 1 for Set 2 for Set 5	 1 2.25 2.25
Discontinuity Persistence Set 1: 3 - 5m Set 2: 3 - 5m Set 5: 3 - 5m	Persistence Factor for Set 1 for Set 2 for Set 5	 4 4 4
Failure Observed - Yes	Failure Observation Parameter	1
	Part 1 Plane Index **Part 1 Wedge Index**	0.5*10.24*1*4*1 = **22.528** 0.81*3.13*2.25*2.25*4*4*1 = **225.895**
Type of Failure Observed on Slope Plane, Wedge, Toppling and Raveling	Failure Observation Parameter Plane Wedge Topple Ravel	 1 1 2 2
Position of Failure - All High	Failure position factor	1.2
Failure Size - all < $0.5m^3$	Failure Size Factor	1
	Part 2 Plane Index **Part 2 Wedge Index** **Part 2 Toppling Index** **Part 2 Ravelling**	1*1.2*1 = **1.2** 1*1.2*1 = **1.2** 1*1.2*2 = **2.4** 1*1.2*2 = **2.4**
Rock Weathering - Moderate	Weathering parameter	1.2
Rock Strength - Strong	Strength Parameter	1
Ground Water - None	Ground Water Parameter	1
Natural Slope Above Cutting - < 20	Natural Slope Parameter	0
Slope Height - 10 - 20m Slope Angle - 70 - 90 Verge Width - < 0.5m Ditch Width - < 0.5m Ditch Depth - < 0.5m Distance to Fence - None	Rock Trap Parameter <0.5m wide 0.5m deep	 0.95
Slope Profile - V. Rough	Slope Profile Parameter	1.2

Table ____ (Cont.) CASE 2, Trial Rock Slope No. 73

Field Data	Hazard Index Parameter	Parameter Value
Berms - None	Berm Parameter	1
Carriageway Width - < 6m	Carriageway Width Parameter	1.2
Sight Lines - <40m	Sight Lines Parameter	1.5
Cutting Type - Box	Cutting Type Parameter	1.05
Associated Hazards - None	Associated Hazards Parameter	1
Road Category - Single track Traffic Volume - 1555 vpd	Traffic Parameter	0.94

Calculation of the Rock Slope Hazard Index

Part 1 plane index + part 2 plane index = 22.528 + 1.2 = **23.728**
Part 1 wedge index + part 2 wedge index = 225.895 + 1.2 = **227.095**
Part 2 toppling index = **2.4**
Part 2 ravelling index = **2.4**

Take into account effects of weathering, strength and ground water for each failure type.
23.728 * 1.2 (weathering) * 1 (strength) * 1(ground water) = **28.474**
227.095 * 1.2 (weathering) * 1 (strength) * 1(ground water) = **272.514**
2.4 * 1.2 (weathering) * 1 (strength) * 1(ground water) = **2.88**
2.4 * 1.2 (weathering) * 1 (strength) * 1(ground water) = **2.88**

Take into account the possibility of failures on any natural slope above cutting. Natural slope parameter = 0 therefore values unchanged

Take into account rock trap, slope profile, berms, carriageway width, sight lines, cutting type, associated hazards.
Plane **23.728** * 0.95 (rock trap) * 1.2 (profile) * 1 (berm) * 1.2 (carriageway) * 1.5 (sight lines) * 1.05 (cutting type) * 1 (associated hazards) = **51.124**
Wedge **272.514** * 0.95 (rock trap) * 1.2 (profile) * 1 (berm) * 1.2 (carriageway) * 1.5 (sight lines) * 1.05 (cutting type) * 1 (associated hazards) = **587.159**
Toppling **2.88** * 0.95 (rock trap) * 1.2 (profile) * 1 (berm) * 1.2 (carriageway) * 1.5 (sight lines) * 1.05 (cutting type) * 1 (associated hazards) = **6.205**
Ravelling **2.88** * 0.95 (rock trap) * 1.2 (profile) * 1 (berm) * 1.2 (carriageway) * 1.5 (sight lines) * 1.05 (cutting type) * 1 (associated hazards) = **6.205**

Add all values togeather and take into account traffic factors.
(51.124 + 587.159 + 6.205 + 6.205) * 0.94 (traffic parameter) = **621.26**

Rock Slope Hazard Index = 621.26

Appendix D Rock Slope Hazard Rating: Field Data Collection Sheets

Rock Slope Hazard Rating Cutting Ref.

Wedge Failure Data Collection Sheet 1 of 2

Road Number Nearest Town

Potential Failure Location

Network Ref.

Network Ref.

Failure Discontinuity Orientation

Set 1
Dip Azimuth

Set 2
Dip Azimuth

Potential Failure Discontinuity Properties

Set 1

Trace Length				
Roughness	Smooth	Rough	V. Rough	
Planarity	Planar	Sl. Curved	Curved	
Strength	Weak	Mod. Weak	Mod. Strong	Strong / v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely
Dilation	Tight	< 2mm	2 - 5mm	> 5mm
Infill	None	Granular	Cohesive	
Water Seepage	Dry	Slight	Major	

Set 2

Trace Length				
Roughness	Smooth	Rough	V. Rough	
Planarity	Planar	Sl. Curved	Curved	
Strength	Weak	Mod. Weak	Mod. Strong	Strong/v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely
Dilation	Tight	< 2mm	2 - 5mm	> 5mm
Infill	None	Granular	Cohesive	
Water Seepage	Dry	Slight	Major	

Potential Failure Rock Properties

Strength	Weak	Mod. Weak	Mod. Strong	Strong/v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely

Potential Failure Dimensions and Location

Height

Width

Rock Face Orientation at Potential Failure

Dip Azimuth

Rock Slope Hazard Rating Cutting Ref.

Wedge Failure Data Collection Sheet 2 of 2

Height of Potential Failure on Face

Rock Slope Profile below Potential Failure

Even (relief < 1m) Rough (relief 1 - 2m) V. rough (relief >2m)

Berms

None Ht. below Potential Failure Width

Verge Width

< 0.5m 0.5 - 1m 1 - 2m 2 - 4m 4 - 6m > 6m

Ditch Width

None < 0.5m 0.5 - 1m 1 - 2m 2 - 4m > 4m

Ditch Depth

None < 0.5m 0.5 - 1m > 1m

Distance to Fence

None < 0.5m 0.5 - 1m 1 - 2m 2 - 4m > 4m

Fence Height

None < 0.5m 0.5 - 1m > 1m

Sight Lines

< 40m 40 - 60m 60 - 100m >100m

4. Total % Hazards Treated

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

5. Effectiveness of Remedial Works

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

Logged By Date

Input By Date

Checked By Date

COMMENTS

Rock Slope Hazard Rating Cutting Ref.

Plane Failure Data Collection Sheet 1 of 2

Road Number Nearest Town

Potential Failure Location

Network Ref.

Network Ref.

Failure Discontinuity Orientation

Dip Azimuth

Potential Failure Discontinuity Properties

Trace Length					
Roughness	Smooth	Rough	V. Rough		
Planarity	Planar	Sl. Curved	Curved		
Strength	Weak	Mod. Weak	Mod. Strong	Strong/v. Strong	
Weathering	Fresh/slight	Moderate	Highly	Completely	
Dilation	Tight	< 2mm	2 - 5mm	> 5mm	
Infill	None	Granular	Cohesive		
Water Seepage	Dry	Slight	Major		

Potential Failure Rock Properties

Strength	Weak	Mod. Weak	Mod. Strong	Strong / v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely

Potential Failure Dimensions and Location

Height

Width

Rock Face Orientation at Potential Failure

Dip Azimuth

Height of Potential Failure on Face

Rock Slope Profile below Potential Failure

Even (relief < 1m) Rough (relief 1 - 2m) V. rough (relief >2m)

Berms

None Ht. below Potential Failure Width

Verge Width

< 0.5m	0.5 - 1m	1 - 2m	2 - 4m	4 - 6m	> 6m

Ditch Width

None	< 0.5m	0.5 - 1m	1 - 2m	2 - 4m	> 4m

Rock Slope Hazard Rating Cutting Ref.

Plane Failure Data Collection Sheet 2 of 2

Ditch Depth

None < 0.5m 0.5 - 1m > 1m

Distance to Fence

None < 0.5m 0.5 - 1m 1 - 2m 2 - 4m > 4m

Fence Height

None < 0.5m 0.5 - 1m > 1m

Sight Lines

< 40m 40 - 60m 60 - 100m >100m

4. Total % Hazards Treated

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

5. Effectiveness of Remedial Works

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

Logged By Date

Input By Date

Checked By Date

COMMENTS

Rock Slope Hazard Rating Cutting Ref.

Toppling Failure Data Collection Sheet 1 of 2

Road Number Nearest Town

Potential Failure Location

Network Ref. Network Ref.

Failure Discontinuity Orientation

Set 1
Dip Azimuth

Set 2
Dip Azimuth

Set 3
Dip Azimuth

Potential Failure Discontinuity Properties

Set 1

Trace Length				
Roughness	Smooth	Rough	V. Rough	
Planarity	Planar	Sl. Curved	Curved	
Strength	Weak	Mod. Weak	Mod. Strong	Strong / v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely
Dilation	Tight	< 2mm	2 - 5mm	> 5mm
Infill	None	Granular	Cohesive	
Water Seepage	Dry	Slight	Major	

Set 2

Trace Length				
Roughness	Smooth	Rough	V. Rough	
Planarity	Planar	Sl. Curved	Curved	
Strength	Weak	Mod. Weak	Mod. Strong	Strong/v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely
Dilation	Tight	< 2mm	2 - 5mm	> 5mm
Infill	None	Granular	Cohesive	
Water Seepage	Dry	Slight	Major	

Set 3

Trace Length				
Roughness	Smooth	Rough	V. Rough	
Planarity	Planar	Sl. Curved	Curved	
Strength	Weak	Mod. Weak	Mod. Strong	Strong/v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely
Dilation	Tight	< 2mm	2 - 5mm	> 5mm
Infill	None	Granular	Cohesive	
Water Seepage	Dry	Slight	Major	

Rock Slope Hazard Rating Cutting Ref.

Toppling Failure Data Collection Sheet 2 of 2

Potential Failure Rock Properties

Strength	Weak	Mod. Weak	Mod. Strong	Strong/v. Strong
Weathering	Fresh/slight	Moderate	Highly	Completely

Potential Failure Dimensions and Location

Height

Width

Rock Face Orientation at Potential Failure

Dip Azimuth

Height of Potential Failure on Face

Rock Slope Profile below Potential Failure

Even (relief < 1m) Rough (relief 1 - 2m) V. rough (relief >2m)

Berms

None Ht. below Potential Failure Width

Verge Width

< 0.5m 0.5 - 1m 1 - 2m 2 - 4m 4 - 6m > 6m

Ditch Width

None < 0.5m 0.5 - 1m 1 - 2m 2 - 4m > 4m

Ditch Depth

None < 0.5m 0.5 - 1m > 1m

Distance to Fence

None < 0.5m 0.5 - 1m 1 - 2m 2 - 4m > 4m

Fence Height

None < 0.5m 0.5 - 1m > 1m

Sight Lines

< 40m 40 - 60m 60 - 100m >100m

Total % Hazards Treated

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

Effectiveness of Remedial Works

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

Logged By Date

Input By Date

Checked By Date

Rock Slope Hazard Rating Cutting Ref.

Ravelling Failure and General Slope Data Collection Sheet 1 of 2

Road Number Nearest Town

Slope Location

Network Ref.

Network Ref.

Potential Ravelling Failure Assessment

Number < 20 20 - 40 40 - 60 60 - 80 80 - 100 > 100

Ht. on Face < 2m 2 - 5m 5 - 10m 10 - 20m > 20m

Profile Below Potential Failure

Even (relief < 1m) Rough (relief 1 - 2m) V. rough (relief >2m)

General Slope Data

Verge Width

< 0.5m 0.5 - 1m 1 - 2m 2 - 4m 4 - 6m > 6m

Ditch Width

None < 0.5m 0.5 - 1m 1 - 2m 2 - 4m > 4m

Ditch Depth

None < 0.5m 0.5 - 1m > 1m

Distance to Fence

None < 0.5m 0.5 - 1m 1 - 2m 2 - 4m > 4m

Fence Height

None < 0.5m 0.5 - 1m > 1m

Sight Lines

< 40m 40 - 60m 60 - 100m >100m

11. Carriageway Width

< 6m 6 - 8m 8 - 10m > 10m

4. Total % Hazards Treated

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

5. Effectiveness of Remedial Works

Rem. Action

< 25% 25 - 50% 51 - 75% 75 - 90% > 90%

Rock Slope Hazard Rating

Cutting Ref.

Plane Failure Data Collection Sheet 2 of 2

Logged By Date

Input By Date

Checked By Date

COMMENTS

Rock Slope Hazard Rating

Discontinuity Survey Data Collection Sheet 1 of 2

Cutting Ref.

Road Number Nearest Town

Slope Location

Network Ref.

Network Ref.

Type	Set	Dip	Azimuth	Trace Length	Dilation	Infill	Roughness	Planarity

Rock Slope Hazard Rating

Discontinuity Survey Data Collection Sheet 1 of 2

Cutting Ref.

Type	Set	Dip	Azimuth	Trace Length	Dilation	Infill	Roughness	Planarity

Logged By Date

Input By Date

Checked By Date

Appendix E Rock Slope Hazard Rating: Parameter Library

The Rock Slope Hazard Rating is calculated using field measurements and parameter values. Field measurements are either used directly in calculations or are factored by other parameters. This appendix lists the values attributed to the various parameters used in calculation of the Hazard Rating. Some of these parameters are used to factor field measurements others are used directly in the calculation process.

Field data, testing data, or local experience may be available which demonstrate that the parameter values given in this appendix are inappropriate. If this is the case then the values derived from such data may be used in deriving the Rating.

E.1 Discontinuity Properties

Discontinuity property parameter values are used in the probabilistic failure calculations that are used estimate the probability of plane wedge and toppling failure. These probabilities are then used in deriving the Rating. Some of the discontinuity property values factor field measurements and others are used directly in the probability calculations.

Table A5.1 Discontinuity Planarity

Planarity	Dip variation	Azm variation
Planar	+ or - 1	+ or - 5
Slightly curved	+ or - 2	+ or - 8
Curved	+ or - 3	+ or - 10

The values given in Table A5.I are used to determine the variation ranges for discontinuity dip and azimuth that are used in the probability calculations.

Table A5.2 Influence of Discontinuity Observations on Ø

Parameter	Selection range	Mean Ø variation
Roughness	smooth	0
	rough	1
	very rough	2
Strength	strong/ v. strong	0
	moderately strong	-1
	moderately weak	-2
	weak	-3
Weathering	fresh/ slight	0
	moderately	-1
	highly	-2
	completely	-3
Infill	granular	-1 to a minimum of 30
	cohesive	Reduce to 30 unless lower

The values given in Table A5.2 are used to influence the mean value of Ø used in probability calculations. The starting mean value of Ø is 35°.

Table A5.3 Assumed relationship between water seepage and water column height used in probability calculations.

Water seepage	Water column height
Dry	0 – 20% h
Slight	20– 50% h
Strong	50 – 75% h
v. strong	75 – 10% h
Where h is the height of the potential failure	

Table A5.3 shows the water column heights that are attributed to various groundwater flow observations. The water column heights are used directly in probability calculations and are varied through the ranges shown in the table.

Table A5.4 Assumed influence of dilation on water column height.

Dilation	Influence on water column height
tight	0
<2mm	0
2 – 5mm	-30%
>5mm	-60%

Table A5.4 shows the assumed influence of discontinuity dilation on water column height at a potential failure. These values are used to factor the water column heights determined from Table A5.3 prior to being used in the probability calculations.

Table A5.5

Parameter	Selection range	Mean Tensile Strength
Strength	strong/ v.strong	350kN/m^2
	moderately strong	250kN/m^2
	moderately weak	150kN/m^2
	weak	50kN/m^2
		Variation in Mean Tensile Strength
Weathering	fresh/ slight	0
	moderately	-10%
	highly	-50%
	completely	-70%

Table A5.5 shows the mean tensile strength values attributed to various discontinuity wall strength categories and how these values are influenced by the weathering state of the discontinuity wall. The tensile strength values derived from these values are used as a value for cohesion in probability calculations.

E.2 Rock Trap Parameter Values

Table A5.6 and A5.7 show the rock trap parameter values for block fall for various rock trap sizes. Table A5.6 is for use on slopes with an even profile and is derived with reference to Mak and Blomfield and Table A5.7 is for use with slopes with a rough profile and has been derived with reference to Ritchie. Tables A5.8 and A5.9 show the rock trap parameter values for larger volume failures for use with slopes with even and rough profiles respectively.

Table A5.6 Rock Trap Parameters for Block Fall for even slopes - applies to block failure ie upto 0.5 m3

Slope Height		<2m	2 - 5m				5 - 10m				10 - 20m				>20m			
Slope angle		any	30 - 45	45 - 60	60 - 70	70 - 90	30 - 45	45 - 60	60 - 70	70 - 90	30 - 45	45 - 60	60 - 70	70 - 90	30 - 45	45 - 60	60 - 70	70 - 90
Trap		Value	**Parameter Values**				**Parameter Values**				**Parameter Values**				**Parameter Values**			
w	d																	
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.5	0	0.8	1	1	0.95	0.9	1	1	1	1	1	1	1	1	1	1	1	1
0.5	0.5	0.1	0.4	0.6	0.5	0.4	0.6	0.7	0.8	0.8	0.8	0.9	0.95	0.95	0.8	0.95	0.95	0.95
1	0	0.3	0.6	0.7	0.65	0.5	0.9	0.95	0.9	0.8	0.95	1	1	1	1	1	1	1
1	0.5	0.001	0.01	0.05	0.05	0.01	0.05	0.1	0.1	0.05	0.3	0.5	0.45	0.4	0.5	0.75	0.7	0.6
1	1	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.01	0.05	0.2	0.15	0.1	0.1	0.5	0.5	0.4
1	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001	0.001	0.1	0.05	0.05	0.001	0.25	0.3	0.2
2	0	0.001	0.1	0.15	0.15	0.1	0.3	0.4	0.4	0.3	0.55	0.6	0.6	0.55	0.8	0.9	0.9	0.75
2	0.5	0.001	0.001	0.001	0.001	0.001	0.05	0.1	0.15	0.05	0.1	0.3	0.25	0.1	0.3	0.6	0.6	0.3
2	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.02	0.01	0.01	0.15	0.15	0.05
2	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001
4	0	0.001	0.001	0.001	0.001	0.001	0.1	0.2	0.2	0.1	0.2	0.3	0.25	0.2	0.3	0.5	0.45	0.3
4	0.5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.001	0.001	0.1	0.1	0.05
4	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001
4	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
6	0	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.05	0.01	0.01	0.15	0.05	0.01	0.1	0.3	0.25	0.1
6	0.5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.01
6	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
6	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
>6	0	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.01	0.001	0.05	0.05	0.01	0.01
>6	0.5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
>6	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
>6	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Note derived with reference to Mak and Blomfield

Note all values Multiplicative.

Table A5.7 Rock Trap Parameters for Block Fall for rough slopes - applies to block failure ie upto 0.5 m3

Slope Height		<2m	2 - 5m				5 - 10m				10 - 20m				>20m			
Slope angle		any	30 - 45	45 - 60	60 - 70	70 - 90	30 - 45	45 - 60	60 - 70	70 - 90	30 - 45	45 - 60	60 - 70	70 - 90	30 - 45	45 - 60	60 - 70	70 - 90
Trap w	d	Value	Parameter Values				Parameter Values				Parameter Values				Parameter Values			
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.5	0	0.8	1	1	0.95	0.9	1	1	1	1	1	1	1	1	1	1	1	1
0.5	0.5	0.1	0.4	0.6	0.5	0.4	0.7	0.8	0.85	0.8	0.9	0.95	1	1	0.9	0.99	0.99	0.99
1	0	0.3	0.7	0.8	0.8	0.6	0.9	0.95	0.9	0.85	1	1	1	1	1	1	1	1
1	0.5	0.001	0.1	0.2	0.2	0.1	0.5	0.75	0.75	0.6	0.7	0.9	0.9	0.7	0.8	1	1	0.8
1	1	0.001	0.001	0.001	0.001	0.001	0.2	0.3	0.3	0.2	0.3	0.5	0.5	0.3	0.5	0.7	0.7	0.5
1	>1	0.001	0.001	0.001	0.001	0.001	0.01	0.1	0.1	0.01	0.05	0.25	0.25	0.05	0.2	0.4	0.4	0.2
2	0	0.001	0.1	0.15	0.15	0.1	0.4	0.6	0.6	0.4	0.55	0.75	0.75	0.6	0.9	1	1	0.9
2	0.5	0.001	0.01	0.05	0.05	0.01	0.15	0.3	0.3	0.2	0.25	0.4	0.45	0.25	0.5	0.85	0.85	0.5
2	1	0.001	0.001	0.001	0.001	0.001	0.05	0.1	0.1	0.05	0.05	0.2	0.2	0.1	0.2	0.4	0.4	0.2
2	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001	0.01	0.1	0.1	0.05	0.1	0.2	0.2	0.1
4	0	0.001	0.01	0.05	0.05	0.01	0.15	0.3	0.3	0.2	0.15	0.4	0.4	0.2	0.3	0.6	0.6	0.3
4	0.5	0.001	0.001	0.001	0.001	0.001	0.05	0.1	0.1	0.05	0.05	0.25	0.3	0.1	0.15	0.4	0.4	0.2
4	1	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.05	0.01	0.01	0.1	0.1	0.05	0.1	0.2	0.25	0.05
4	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.01	0.01	0.05	0.05	0.01
6	0	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.05	0.01	0.01	0.15	0.15	0.01	0.2	0.4	0.4	0.15
6	0.5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.001	0.1	0.2	0.2	0.05
6	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.05	0.01
6	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001
>6	0	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.001	0.05	0.1	0.1	0.05
>6	0.5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.05	0.01
>6	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001
>6	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Note derived with reference to Ritchie

Note all values Multiplicative.

Table A5.8 Rock Trap Parameters for Failure volumes for even slopes

Slope Height		<2m	2 - 5m				5 - 10m				10 - 20m				>20m			
Failure Volume			0.5	1	3	6	0.5	1	3	6	0.5	1	3	6	0.5	1	3	6
Radius		any	0.97721	1.38198	2.39365	3.38514	1.19683	1.69257	2.93162	4.14593	1.38198	1.95441	3.38514	4.78731	1.69257	2.39365	4.14593	5.86323
Trap		Values	**Parameter Values**				**Parameter Values**				**Parameter Values**				**Parameter Values**			
w	d																	
0	0	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
0.5	0	**0.9**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
0.5	0.5	**0.1**	**0.6**	**0.8**	**1**	**1**	**0.7**	**0.95**	**1**	**1**	**0.9**	**1**	**1**	**1**	**0.95**	**1**	**1**	**1**
1	0	**0.3**	**0.7**	**1**	**1**	**1**	**0.95**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
1	0.5	**0.001**	**0.05**	**0.4**	**0.7**	**1**	**0.1**	**0.5**	**0.9**	**1**	**0.5**	**0.7**	**1**	**1**	**0.75**	**0.95**	**1**	**1**
1	1	**0.001**	**0.001**	**0.001**	**0.01**	**0.25**	**0.05**	**0.1**	**0.4**	**0.6**	**0.2**	**0.4**	**0.7**	**1**	**0.5**	**0.7**	**1**	**1**
1	>1	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.01**	**0.05**	**0.1**	**0.3**	**0.1**	**0.2**	**0.4**	**0.7**	**0.25**	**0.5**	**1**	**1**
2	0	**0.001**	**0.15**	**0.4**	**1**	**1**	**0.4**	**0.6**	**1**	**1**	**0.6**	**1**	**1**	**1**	**0.9**	**1**	**1**	**1**
2	0.5	**0.001**	**0.001**	**0.01**	**0.05**	**0.3**	**0.1**	**0.2**	**0.4**	**0.7**	**0.3**	**0.5**	**0.7**	**0.9**	**0.6**	**0.8**	**0.95**	**1**
2	1	**0.001**	**0.001**	**0.001**	**0.01**	**0.15**	**0.001**	**0.001**	**0.05**	**0.2**	**0.05**	**0.1**	**0.3**	**0.5**	**0.15**	**0.3**	**0.45**	**0.6**
2	>1	**0.001**	**0.001**	**0.001**	**0.001**	**0.1**	**0.001**	**0.001**	**0.01**	**0.1**	**0.001**	**0.01**	**0.1**	**0.25**	**0.01**	**0.05**	**0.15**	**0.4**
4	0	**0.001**	**0.001**	**0.001**	**0.05**	**0.2**	**0.2**	**0.3**	**0.6**	**1**	**0.3**	**0.4**	**0.5**	**1**	**0.5**	**0.7**	**1**	**1**
4	0.5	**0.001**	**0.001**	**0.001**	**0.01**	**0.1**	**0.001**	**0.001**	**0.01**	**0.2**	**0.05**	**0.1**	**0.25**	**0.4**	**0.01**	**0.05**	**0.4**	**0.6**
4	1	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.001**	**0.001**	**0.001**	**0.01**	**0.001**	**0.01**	**0.05**	**0.2**	**0.01**	**0.05**	**0.1**	**0.3**
4	>1	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.001**	**0.001**	**0.05**	**0.15**
6	0	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.1**	**0.15**	**0.3**	**0.15**	**0.2**	**0.4**	**0.7**	**0.3**	**0.4**	**0.6**	**0.9**
6	0.5	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.001**	**0.01**	**0.1**	**0.25**	**0.001**	**0.01**	**0.05**	**0.2**
6	1	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.05**	**0.01**	**0.001**	**0.001**	**0.001**	**0.05**
6	>1	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**
>6	0	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.05**	**0.1**	**0.2**	**0.4**	**0.05**	**0.1**	**0.3**	**0.4**
>6	0.5	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.05**	**0.1**	**0.001**	**0.01**	**0.05**	**0.1**
>6	1	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.01**	**0.001**	**0.001**	**0.01**	**0.05**
>6	>1	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Note:- For failure masses that form a half cone spoil heap at the toe of the slope.
where height of half cone = radius for 2 - 5m slopes, 2/3 radius for 5 - 10m slopes, 1/2 radius for 10 - 20m slopes and 1/3 radius for > 20m slopes.

Note all Values Multiplicative.

Table A5.9 Rock Trap Parameters for Failure volumes for rough slopes

Slope Height		<2m	2 - 5m				5 - 10m				10 - 20m				>20m			
Failure Volume			0.5	1	3	6	0.5	1	3	6	0.5	1	3	6	0.5	1	3	6
Radius		any	0.97721	1.38198	2.39365	3.38514	1.19683	1.69257	2.93162	4.14593	1.38198	1.95441	3.38514	4.78731	1.69257	2.39365	4.14593	5.86323
Trap		Values	**Parameter Values**				**Parameter Values**				**Parameter Values**				**Parameter Values**			
w	d																	
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.5	0	0.9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.5	0.5	0.1	0.6	0.8	1	1	0.8	0.95	1	1	0.95	1	1	1	0.99	1	1	1
1	0	0.3	0.8	1	1	1	0.95	1	1	1	1	1	1	1	1	1	1	1
1	0.5	0.001	0.2	0.4	0.7	1	0.75	0.9	1	1	0.9	1	1	1	1	1	1	1
1	1	0.001	0.001	0.001	0.01	0.25	0.3	0.4	0.7	0.9	0.5	0.7	0.95	1	0.7	0.8	1	1
1	>1	0.001	0.001	0.001	0.001	0.05	0.1	0.2	0.4	0.6	0.25	0.4	0.6	0.8	0.4	0.6	1	1
2	0	0.001	0.15	0.4	1	1	0.6	0.8	1	1	0.75	1	1	1	1	1	1	1
2	0.5	0.001	0.05	0.1	0.15	0.3	0.3	0.4	0.7	0.9	0.4	0.6	0.8	0.95	0.85	1	1	1
2	1	0.001	0.001	0.001	0.01	0.15	0.1	0.2	0.4	0.6	0.2	0.3	0.45	0.6	0.4	0.6	0.8	1
2	>1	0.001	0.001	0.001	0.001	0.1	0.01	0.05	0.1	0.2	0.1	0.01	0.1	0.25	0.2	0.4	0.6	0.8
4	0	0.001	0.05	0.1	0.15	0.3	0.3	0.45	0.7	1	0.4	0.55	0.7	0.8	0.6	0.75	1	1
4	0.5	0.001	0.001	0.001	0.01	0.1	0.1	0.2	0.4	0.6	0.25	0.4	0.55	0.7	0.4	0.6	0.8	0.95
4	1	0.001	0.001	0.001	0.001	0.01	0.05	0.1	0.15	0.3	0.1	0.2	0.4	0.6	0.2	0.4	0.6	0.7
4	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.1	0.2	0.4	0.05	0.1	0.2	0.4
6	0	0.001	0.001	0.001	0.001	0.001	0.05	0.1	0.15	0.3	0.15	0.3	0.5	0.7	0.4	0.6	0.8	0.9
6	0.5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.1	0.2	0.4	0.2	0.4	0.6	0.8
6	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.1	0.05	0.1	0.2	0.4
6	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.1	0.2
>6	0	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.05	0.1	0.2	0.4	0.1	0.2	0.4	0.6
>6	0.5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.05	0.1	0.05	0.1	0.2	0.4
>6	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.05	0.1	0.2
>6	>1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Note:- For failure masses that form a half cone spoil heap at the toe of the slope.
where height of half cone = radius for 2 - 5m slopes, 2/3 radius for 5 - 10m slopes, 1/2 radius for 10 - 20m slopes and 1/3 radius for > 20m slopes.

Note all Values Multiplicative.

E.3 Road Geometry Parameter Values

In the absence of experimental data on driver reaction to rock falls the likelihood values given in table A5.10 have been derived from stopping distance data.

Table A5.10 Assumed relationship between sight lines and the likelihood of stopping before hitting an obstruction.

Sight lines	Likelihood values
40 – 60m	0.75 (mean of variation from 0.5 to 1)
60 – 100m	0.3 (mean of variation from 0.05 to 0.5)
>100m	0.005

The values shown in Table A5.10 are used in the vehicle probability calculations.

Appendix F Derivation of Traffic Probability Expressions

Derivation of Traffic Probability Expressions

The expression for determining the probability of a vehicle occupying a 40m stretch of road, used in calculation of the Hazard Rating, was derived as follows:

The number of vehicles passing a point on a given stretch of road in a 24 hour period is available from traffic counter data. Let the number of vehicles passing the counter in 24 hours be x.

Distribution of traffic flow is not even through a 24 hour period. More traffic will pass the counter during the day period (0700 - 2100) than during the night period. Let the percentage of vehicles passing the counter during the day period be z.

The number of vehicles that pass the counter per hour during the day period can be calculated from:

$$z.x\ /\ 14$$

If the average speed of vehicles on the road is V_s and the length of the section of road is R_1 the number of vehicles on the section of road can be calculated from:

$$\frac{R_1.z.x}{14Vs}$$

If the average length of a vehicle is VI the total length of road occupied by vehicles is given by the total number of vehicles multiplied by the average vehicle length:

$$\frac{R_1.z.x.V_1}{14Vs}$$

The probability that a vehicle is occupying a given position on the road is determined by dividing the total amount of road occupied by vehicles at an instant by the total length of road:

$$\frac{R_1.z.x.V_1}{14Vs.R_1} = \frac{z.x.V_1}{14Vs}$$

The probability of a vehicle occupying one of n positions on the road can be calculated b) multiplying the probability of a vehicle occupying one position by n as follows:

$$\frac{n.z.x.V_1}{14Vs}$$

In the 40m up carriageway of a potential failure there are $40/V_1$ possible vehicle positions. The probability of a vehicle occupying one of these positions can be calculated by multiplying the probability of a vehicle occupying one position by $40/V_1$ as follows:

$$\frac{40.z.x.V_1}{V_1\,14Vs} = \frac{40.z.x}{14Vs}$$

If vehicle speed is in kmh^{-1} then the 40 will become 0.04.

This is the expression used in the vehicle probability calculations used in deriving the Hazard Rating. This expression can only be used up to the probability limit of 1. If traffic density on a road is such that the average spacing between vehicles falls below 40m then the expression will derive a value of > 1. This is impossible and a value of 1 should be used in the Rating calculations.

Appendix G Rock Slope Hazard Index Trial Results

TABLE A7.1 TRL Results

A830 Rock Slope Hazard Inventory Trial Hazard Indices Tabulated According to Rock Slope Reference Number				
Rock Slope	Rock Slope	Network Reference		Rock Slope
Reference No.	Hazard Index	Start	End	Height Category
1	0.18	1561 - 835	1561 - 785	5 - 10m
2	0.003	1561 - 600	1561 - 574	2 - 5m
3	0.008	1561 - 280	1561 - 373	5 - 10m
4	0.02	1561 - 260	1561 - 132	5 - 10m
5	0.14	1561 - 260	1561 - 358	5 - 10m
6	0.04	N/A	N/A	5 - 10m
7	0.01	N/A	N/A	2 - 5m
8	1.59	N/A	N/A	5 - 10m
9	4.73	N/A	N/A	5 - 10m
10	0.21	N/A	N/A	10 - 20m
11	0.04	N/A	N/A	5 - 10m
12	0.002	N/A	N/A	5 - 10m
13	0.004	N/A	N/A	2 - 5m
14	0.003	N/A	N/A	2 - 5m
15	0.02	N/A	N/A	5 - 10m
16	0.02	N/A	N/A	5 - 10m
17	0.004	N/A	N/A	5 - 10m
18	0.48	N/A	N/A	>20m
19	11.94	N/A	N/A	10 - 20m
20	0.004	N/A	N/A	5 - 10m
21	23.7	1380 - 610	1380 - 590	5 - 10m
22	0.313	1380 - 500	1380 - 487	2 - 5m
23	0	1350 - 1550	1350 - 1580	2 - 5m
24	8.81	1350 - 960	1350 - 946	2 - 5m
25	9.34	1350 - 300	1350 - 296	2 - 5m
26	0	1350 - 140	1350 - 127	5 - 10m
27	0.45	1325 - 770	1325 - 754	5 - 10m
28	0.007	1310 - 1100	1310 - 425	2 - 5m
29	0.009	1085 - 480	1085 - 440	2 - 5m
30	8.85	1080 - 250	1080 - 240	2 - 5m
31	0.15	1080 - 130	1080 - 047	2 - 5m
32	5.35	1065 - 1320	1065 - 1298	10 - 20m
33	3.31	1065 - 957	1065 - 1040	2 - 5m
34	7.24	1065 - 740	1065 - 790	2 - 5m
35	25.06	1055 - 720	1055 - 830	2 - 5m
36	15.19	1055 - 580	1055 - 505	5 - 10m
37	24.05	1045 - 1375	1045 - 1681	5 - 10m
38	0.005	1045 - 1200	1045 - 1220	2 - 5m
39	0.081	1045 - 1000	1045 - 982	2 - 5m
40	27.72	1045 - 880	1045 - 815	10 - 20m

TABLE A7.1 TRL Results

A830 Rock Slope Hazard Inventory Trial
Hazard Indices Tabulated According to Rock Slope Reference Number

Rock Slope Reference No.	Rock Slope Hazard Index	Network Reference Start	Network Reference End	Rock Slope Height Category
41	0.32	1045 - 700	1045 - 678	2 - 5m
42	1.02	1045 - 620	1045 - 598	5 - 10m
43	12.71	1045 - 426	1045 - 304	5 - 10m
44	33.99	1045 - 179	1045 - 101	10 - 20m
45	0.57	1035 - 20	1035 - 31	5 - 10m
46	52.26	1035 - 2000	1035 - 1950	10 - 20m
47	1.54	1035 - 1875	1035 - 1821	10 - 20m
48	22.45	1035 - 1770	1035 - 1710	5 - 10m
49	0.14	1035 - 1551	1035 - 1441	5 - 10m
50	0.17	1035 - 1100	1035 - 1030	10 - 20m
51	9.8	1035 - 935	1035 - 820	5 - 10m
52	0.071	1035 - 940	1035 - 830	5 - 10m
53	47.64	1035 - 490	1035 - 360	5 - 10m
54	0.402	1020 - 2220	1020 - 2265	5 - 10m
55	2.92	1020 - 2200	1020 - 2182	2 - 5m
56	0.35	1020 - 2250	1020 - 2235	2 - 5m
57	0	1020 - 1960	1020 - 1940	2 - 5m
58	46.16	1020 - 1940	1020 - 1810	10 - 20m
59	0.003	1020 - 1750	1020 - 1732	<2m
60	3.48	1020 - 1750	1020 - 1708	2 - 5m
61	3.64	1020 - 1650	1020 - 1612	2 - 5m
62	6.78	1020 - 1645	1020 - 1627	2 - 5m
63	5.81	1020 - 1614	1020 - 1579	2 - 5m
64	0.53	1020 - 1570	1020 - 1530	2 - 5m
65	1.32	1020 - 1482	1020 - 1464	2 - 5m
66	5.63	1020 - 1464	1020 - 1439	5 - 10m
67	1.15	1020 - 1360	1020 - 1452	2 - 5m
68	0.79	1020 - 1300	1020 - 1278	2 - 5m
69	0.92	1020 - 1260	1020 - 1230	2 - 5m
70	0.71	1020 - 1195	1020 - 1125	5 - 10m
71	171.1	1020 - 1090	1020 - 1050	2 - 5m
72	0.94	1020 - 1057	1020 - 1090	2 - 5m
73	621.26	1020 - 980	1020 - 910	10 - 20m
74	10.66	1020 - 912	1020 - 980	2 - 5m
75	276.5	1020 - 802	1020 - 735	5 - 10m
76	11.95	1020 - 785	1020 - 802	2 - 5m
77	2.84	1020 - 690	1020 - 585	2 - 5m
78	3.69	1020 - 600	1020 - 535	2 - 5m
79	12.3	1020 - 498	1020 - 600	>20m

TABLE A7.1 TRL Results

A830 Rock Slope Hazard Inventory Trial Hazard Indices Tabulated According to Rock Slope Reference Number				
Rock Slope Reference No.	Rock Slope Hazard Index	Network Reference Start	End	Rock Slope Height Category
80	64.42	1020 - 1540	1020 - 1485	5 - 10m
81	3.56	1020 - 250	1020 - 400	2 - 5m
82	7.05	1020 - 040	1020 - 010	2 - 5m
83	1.39	1006 - 1592	1006 - 1577	2 - 5m
84	0.002	1006 - 1302	1006 - 1185	>20m
85	0.37	1006 - 1154	1006 - 1066	10 - 20m
86	0.003	1006 - 1239	1006 - 1144	>20m
87	0.001	1006 - 734	1006 - 638	5 - 10m
88	0.009	1006 - 598	1006 - 520	5 - 10m
89	0.009	1006 - 514	1006 - 574	5 - 10m
90	0.007	1006 - 434	1006 - 311	10 - 20m
91	0.004	1006 - 489	1006 - 404	5 - 10m
92	0.02	1006 - 216	1006 - 000	>20m
93	0.003	1006 - 000	1006 - 088	10 - 20m
94	2.68	0895 - 2200	0895 - 2130	2 - 5m
95	0.003	0895 - 2130	0895 - 2187	2 - 5m
96	0.26	0895 - 2000	0895 - 2047	2 - 5m
97	1.69	0895 - 2057	0895 - 2000	5 - 10m
98	0.58	0895 - 1670	0895 - 1700	2 - 5m
99	3.06	0895 - 110	0895 - 185	2 - 5m
100	39.61	0895 - 065	0895 - 130	5 - 10m
101	8.69	0860 - 5640	0860 - 5595	5 - 10m
102	4.08	0860 - 5500	0860 - 5445	5 - 10m
103	0.28	0860 - 5575	0860 - 5608	2 - 5m
104	1.44	0860 - 5060	0860 - 5000	5 - 10m
105	2.31	0860 - 4280	0860 - 4257	5 - 10m
106	4.33	0860 - 4180	0860 - 4237	5 - 10m
107	20.2	0860 - 4135	0860 - 3979	10 - 20m
108	2.42	0860 - 3910	0860 - 3854	2 - 5m
109	0.66	0860 - 3785	0860 - 3746	2 - 5m
110	0.26	0860 - 3715	0860 - 3671	2 - 5m
111	2.12	0860 - 3130	0860 - 3070	2 - 5m
112	0.66	0860 - 2995	0860 - 2970	2 - 5m
113	1.13	0860 - 2790	0860 - 2747	2 - 5m
114	2.29	0860 - 2690	0860 - 2640	5 - 10m
115	30.05	0860 - 2640	0860 - 2542	5 - 10m
116	0.007	0860 - 2540	0860 - 2478	2 - 5m
117	0.45	0860 - 2230	0860 - 2021	2 - 5m
118	0.51	0860 - 2100	0860 - 2044	2 - 5m

TABLE A7.1 TRL Results

A830 Rock Slope Hazard Inventory Trial Hazard Indices Tabulated According to Rock Slope Reference Number				
Rock Slope Reference No.	Rock Slope Hazard Index	Network Reference Start	 End	Rock Slope Height Category
119	0	0860 - 1780	0860 - 1740	2 - 5m
120	4.98	0860 - 1700	0860 - 1586	5 - 10m
121	2.16	0860 - 1500	0860 - 1405	5 - 10m
122	5.62	0860 - 1370	0860 - 1320	5 - 10m
123	24.45	0860 - 1200	0860 - 1145	5 - 10m
124	4.14	0860 - 1116	0860 - 1072	2 - 5m
125	2.03	0860 - 1085	0860 - 1032	5 - 10m
126	6.73	0860 - 980	0860 - 925	5 - 10m
127	0.41	0860 - 766	0860 - 756	2 - 5m
128	0.27	0860 - 492	0860 - 459	2 - 5m
129	2.03	0860 - 422	0860 - 387	2 - 5m
130	1.67	0860 - 362	0860 - 317	5 - 10m
131	6.79	0860 - 292	0860 - 247	5 - 10m
132	13.79	0860 - 247	0860 - 142	5 - 10m
133	0.27	0860 - 135	0860 - 112	2 - 5m
134	1.08	0850 - 1840	0850 - 1815	2 - 5m
135	5.59	0850 - 1810	0850 - 1910	5 - 10m
136	0.29	0850 - 1650	0850 - 1625	2 - 5m
137	4.86	0850 - 1600	0850 - 1473	5 - 10m
138	2.48	0850 - 1450	0850 - 1487	5 - 10m
139	1.45	0850 - 900	0850 - 811	5 - 10m
140	0.39	0850 - 584	0850 - 555	2 - 5m
141	3.29	0850 - 491	0850 - 403	2 - 5m
142	7.65	0850 - 393	0850 - 288	5 - 10m
143	3.58	0850 - 267	0850 - 150	5 - 10m
144	2.6	0850 - 140	0850 - 057	10 - 20m
145	7.6	0850 - 050	0840 - 2550	10 - 20m
146	0.2	0840 - 2500	0840 - 2463	2 - 5m
147	2.43	0840 - 2480	0840 - 2453	10 - 20m
148	0.08	0840 - 2380	0840 - 2254	2 - 5m
149	0.27	0840 - 2100	0840 - 2034	2 - 5m
150	1.72	0840 - 1860	0840 - 1774	10 - 20m
151	1.87	0840 - 1560	0840 - 1446	5 - 10m
152	14.61	0835 - 1480	0835 - 1230	5 - 10m
153	0.47	0835 - 860	0835 - 824	2 - 5m
154	0.39	0835 - 430	0835 - 385	2 - 5m
155	2.04	0835 - 240	0835 - 190	5 - 10m
156	0.14	0835 - 080	0835 - 050	2 - 5m
157	0.35	0825 - 1770	0825 - 1755	2 - 5m

TABLE A7.1 TRL Results

A830 Rock Slope Hazard Inventory Trial
Hazard Indices Tabulated According to Rock Slope Reference Number

Rock Slope Reference No.	Rock Slope Hazard Index	Network Reference Start	End	Rock Slope Height Category
158	0.42	0825 - 1410	0825 - 1385	2 - 5m
159	0.002	0825 - 1310	0825 - 1338	2 - 5m
160	0.006	0825 - 1190	0825 - 1072	2 - 5m
161	4.49	0825 - 0880	0825 - 0848	5 - 10m
162	0.07	0825 - 0840	0825 - 0827	2 - 5m
163	9.23	0825 - 120	0825 - 020	10 - 20m
164	8.75	0825 - 020	0825 - 120	10 - 20m
165	0.78	0815 - 2620	0815 - 2545	5 - 10m
166	0.004	0815 - 2500	0815 - 2468	2 - 5m
167	0.003	0815 - 2390	0815 - 2355	2 - 5m
168	0.45	0815 - 2300	0815 - 2255	5 - 10m
169	0.85	0815 - 930	0815 - 836	5 - 10m
170	7.06	0815 - 1825	0815 - 1745	5 - 10m
171	0.69	0815 - 1625	0815 - 1563	5 - 10m
172	1	0851 - 1586	0851 - 1514	10 - 20m
173	0.007	0815 - 1540	0815 - 1508	5 - 10m
174	0.28	0815 - 1592	0815 - 1532	5 - 10m
175	0.06	0815 - 1653	0815 - 1575	5 - 10m
176	0.005	0815 - 900	0815 - 920	2 - 5m
177	0.0008	0815 - 463	0815 - 426	2 - 5m
178	0.004	0800 - 1100	0800 - 1227	2 - 5m
179	0	0800 - 880	0800 - 775	2 - 5m

TABLE A7.2 Consulatant A Results

A830 Rock Slope Hazard Inventory Trial Hazard Indices Tabulated According to Rock Slope Reference Number				
Rock Slope	Rock Slope	Network Reference		Rock Slope
Reference No.	Hazard Index	Start	End	Height Category
1	0.07	1561 - 835	1561 - 785	5 - 10m
4	0.01	1561 - 260	1561 - 132	5 - 10m
7	0.04	N/A	N/A	2 - 5m
8	0.063	N/A	N/A	5 - 10m
10	0.16	N/A	N/A	10 - 20m
12	0.065	N/A	N/A	5 - 10m
14	0.003	N/A	N/A	2 - 5m
17	0	N/A	N/A	5 - 10m
18	0.002	N/A	N/A	>20m
19	1.851	N/A	N/A	10 - 20m
22	0.664	1380 - 500	1380 - 487	2 - 5m
24	0.486	1350 - 960	1350 - 946	2 - 5m
26	0.1	1350 - 140	1350 - 127	5 - 10m
28	0.665	1310 - 1100	1310 - 425	2 - 5m
29	3.092	1085 - 480	1085 - 440	2 - 5m
30	1.996	1080 - 250	1080 - 240	2 - 5m
34	4.079	1065 - 740	1065 - 790	2 - 5m
38	0	1045 - 1200	1045 - 1220	2 - 5m
39	0.384	1045 - 1000	1045 - 982	2 - 5m
40	53.429	1045 - 880	1045 - 815	10 - 20m
42	7.309	1045 - 620	1045 - 598	5 - 10m
44	5.417	1045 - 179	1045 - 101	10 - 20m
46	64.125	1035 - 2000	1035 - 1950	10 - 20m
50	0.054	1035 - 1100	1035 - 1030	10 - 20m
53	83.222	1035 - 490	1035 - 360	5 - 10m
55	5.732	1020 - 2200	1020 - 2182	2 - 5m
57	0.227	1020 - 1960	1020 - 1940	2 - 5m
58	2.456	1020 - 1940	1020 - 1810	10 - 20m
59	0.017	1020 - 1750	1020 - 1732	<2m
60	11.128	1020 - 1750	1020 - 1708	2 - 5m
61	16.004	1020 - 1650	1020 - 1612	2 - 5m
62	0	1020 - 1645	1020 - 1627	2 - 5m
63	1.308	1020 - 1614	1020 - 1579	2 - 5m
66	4.616	1020 - 1464	1020 - 1439	5 - 10m
68	0.004	1020 - 1300	1020 - 1278	2 - 5m
71	95.583	1020 - 1090	1020 - 1050	2 - 5m
72	0	1020 - 1057	1020 - 1090	2 - 5m
73	602.227	1020 - 980	1020 - 910	10 - 20m
75	249.603	1020 - 802	1020 - 735	5 - 10m
76	113.482	1020 - 785	1020 - 802	2 - 5m

TABLE A7.2 Consulatant A Results

A830 Rock Slope Hazard Inventory Trial
Hazard Indices Tabulated According to Rock Slope Reference Number

Rock Slope Reference No.	Rock Slope Hazard Index	Network Reference Start	End	Rock Slope Height Category
81	3.822	1020 - 250	1020 - 400	2 - 5m
82	1.285	1020 - 040	1020 - 010	2 - 5m
84	0.001	1006 - 1302	1006 - 1185	>20m
88	0.008	1006 - 598	1006 - 520	5 - 10m
89	0.0001	1006 - 514	1006 - 574	5 - 10m
92	0.168	1006 - 216	1006 - 000	>20m
93	0.002	1006 - 000	1006 - 088	10 - 20m
98	0.386	0895 - 1670	0895 - 1700	2 - 5m
99	0.41	0895 - 110	0895 - 185	2 - 5m
100	211.428	0895 - 065	0895 - 130	5 - 10m
101	950.076	0860 - 5640	0860 - 5595	5 - 10m
103	5.781	0860 - 5575	0860 - 5608	2 - 5m
104	0.018	0860 - 5060	0860 - 5000	5 - 10m
107	3048.947	0860 - 4135	0860 - 3979	10 - 20m
111	22.299	0860 - 3130	0860 - 3070	2 - 5m
112	4.391	0860 - 2995	0860 - 2970	2 - 5m
113	27.831	0860 - 2790	0860 - 2747	2 - 5m
115	2.393	0860 - 2640	0860 - 2542	5 - 10m
118	65.239	0860 - 2100	0860 - 2044	2 - 5m
120	39.109	0860 - 1700	0860 - 1586	5 - 10m
124	31.486	0860 - 1116	0860 - 1072	2 - 5m
130	0.214	0860 - 362	0860 - 317	5 - 10m
133	0.004	0860 - 135	0860 - 112	2 - 5m
135	0.027	0850 - 1810	0850 - 1910	5 - 10m
137	0.736	0850 - 1600	0850 - 1473	5 - 10m
138	0	0850 - 1450	0850 - 1487	5 - 10m
139	2.217	0850 - 900	0850 - 811	5 - 10m
143	2.176	0850 - 267	0850 - 150	5 - 10m
145	479.433	0850 - 050	0840 - 2550	10 - 20m
147	108.508	0840 - 2480	0840 - 2453	10 - 20m
152	5.798	0835 - 1480	0835 - 1230	5 - 10m
157	0.003	0825 - 1770	0825 - 1755	2 - 5m
158	0.003	0825 - 1410	0825 - 1385	2 - 5m
160	1.642	0825 - 1190	0825 - 1072	2 - 5m
163	24.821	0825 - 120	0825 - 020	10 - 20m
168	0.004	0815 - 2300	0815 - 2255	5 - 10m
169	1.995	0815 - 930	0815 - 836	5 - 10m
171	0.079	0815 - 1625	0815 - 1563	5 - 10m
174	0.074	0815 - 1592	0815 - 1532	5 - 10m
179	0.002	0800 - 880	0800 - 775	2 - 5m

TABLE A7.3 Consultant B Results

A830 Rock Slope Hazard Inventory Trial
Hazard Indices Tabulated According to Rock Slope Reference Number

Rock Slope Reference No.	Rock Slope Hazard Index	Network Reference Start	End	Rock Slope Height Category
4	0.063	1561 - 260	1561 - 132	5 - 10m
5	0.267	1561 - 260	1561 - 358	5 - 10m
7	0.438	N/A	N/A	2 - 5m
8	4.568	N/A	N/A	5 - 10m
17	47.851	N/A	N/A	5 - 10m
19	12.088	N/A	N/A	10 - 20m
20	0.046	N/A	N/A	5 - 10m
26	77.429	1350 - 140	1350 - 127	5 - 10m
32	10.613	1065 - 1320	1065 - 1298	10 - 20m
34	2993.77	1065 - 740	1065 - 790	2 - 5m
39	59.597	1045 - 1000	1045 - 982	2 - 5m
43	21.557	1045 - 426	1045 - 304	5 - 10m
44	6.916	1045 - 179	1045 - 101	10 - 20m
45	0.104	1035 - 20	1035 - 31	5 - 10m
46	477.814	1035 - 2000	1035 - 1950	10 - 20m
47	173.716	1035 - 1875	1035 - 1821	10 - 20m
48	56.338	1035 - 1770	1035 - 1710	5 - 10m
50	0.113	1035 - 1100	1035 - 1030	10 - 20m
53	157.288	1035 - 490	1035 - 360	5 - 10m
55	1.421	1020 - 2200	1020 - 2182	2 - 5m
57	1.251	1020 - 1960	1020 - 1940	2 - 5m
58	7.236	1020 - 1940	1020 - 1810	10 - 20m
61	7.425	1020 - 1650	1020 - 1612	2 - 5m
66	6.819	1020 - 1464	1020 - 1439	5 - 10m
68	0.406	1020 - 1300	1020 - 1278	2 - 5m
71	54.073	1020 - 1090	1020 - 1050	2 - 5m
72	12.996	1020 - 1057	1020 - 1090	2 - 5m
73	8.945	1020 - 980	1020 - 910	10 - 20m
74	19.816	1020 - 912	1020 - 980	2 - 5m
75	3.358	1020 - 802	1020 - 735	5 - 10m
76	14.122	1020 - 785	1020 - 802	2 - 5m
82	3.265	1020 - 040	1020 - 010	2 - 5m
84	0.008	1006 - 1302	1006 - 1185	>20m
85	219.441	1006 - 1154	1006 - 1066	10 - 20m
89	0.007	1006 - 514	1006 - 574	5 - 10m
92	2.419	1006 - 216	1006 - 000	>20m
93	0.006	1006 - 000	1006 - 088	10 - 20m
96	5.226	0895 - 2000	0895 - 2047	2 - 5m
99	0.523	0895 - 110	0895 - 185	2 - 5m

APPENDIX 7

TABLE A7.3 Consultant B Results

A830 Rock Slope Hazard Inventory Trial Hazard Indices Tabulated According to Rock Slope Reference Number				
Rock Slope Reference No.	Rock Slope Hazard Index	Network Reference Start	End	Rock Slope Height Category
100	28.623	0895 - 065	0895 - 130	5 - 10m
102	12.084	0860 - 5500	0860 - 5445	5 - 10m
103	3.374	0860 - 5575	0860 - 5608	2 - 5m
104	1.052	0860 - 5060	0860 - 5000	5 - 10m
107	236.132	0860 - 4135	0860 - 3979	10 - 20m
109	3.672	0860 - 3785	0860 - 3746	2 - 5m
112	0.149	0860 - 2995	0860 - 2970	2 - 5m
113	8.721	0860 - 2790	0860 - 2747	2 - 5m
115	0.113	0860 - 2640	0860 - 2542	5 - 10m
116	8.189	0860 - 2540	0860 - 2478	2 - 5m
120	70.64	0860 - 1700	0860 - 1586	5 - 10m
122	8.819	0860 - 1370	0860 - 1320	5 - 10m
126	10.743	0860 - 980	0860 - 925	5 - 10m
130	12.834	0860 - 362	0860 - 317	5 - 10m
134	5.781	0850 - 1840	0850 - 1815	2 - 5m
138	45.531	0850 - 1450	0850 - 1487	5 - 10m
140	0.352	0850 - 584	0850 - 555	2 - 5m
141	42.897	0850 - 491	0850 - 403	2 - 5m
143	66.768	0850 - 267	0850 - 150	5 - 10m
145	256.166	0850 - 050	0840 - 2550	10 - 20m
147	46.132	0840 - 2480	0840 - 2453	10 - 20m
148	1.519	0840 - 2380	0840 - 2254	2 - 5m
151	16.32	0840 - 1560	0840 - 1446	5 - 10m
152	23.103	0835 - 1480	0835 - 1230	5 - 10m

Appendix H Rock Slope Hazard Index Update

H.1 Introduction

This Appendix provides an update to the original Transport Research Laboratory (TRL) Project Report on 'Rock Slope Risk Assessment' (McMillan, 1995). This update presents a ravelling criterion for the Rock Slope Hazard Index (RSHI) and necessary additions to the data collection process.

It should be noted that the descriptions of the rock are all to BS 5930:1999 as this was applicable at the time of development of the RSHI.

H.2 Background

In 1993 TRL were commissioned by the Scottish Office Development Department, now Transport Scotland, to develop a risk assessment system and maintenance management strategy for highway rock slopes. This work culminated in the development and trialling of the Rock Slope Hazard Index (RSHI V1.0) system between 1993 and 1995 (McMillan, 1995; Marshall, 1995; McMillan and Matheson, 1997; McMillan et al., 1998). Following the successful trial and independent review (BS 5930:1999; McMillan, 1995) the RSHI was implemented in the Northwest Highlands of Scotland.

Between 1995 and 2000 in excess of 1500 rock slopes, in both Scotland and England, were inspected and assessed using the RSHI by TRL for roads and during work on developing a quarry version of the RSHI, for the assessment of quarry excavations (Butler et al., 2000). During this work ravelling was identified as probably the most frequently observed significant hazard on rock slopes.

The RSHI (V1.0) assessed the hazard presented by each of the failure modes (plane, wedge and toppling) by following two assessment streams for each mode of failure:

1. Theoretical prediction of hazard potential.
2. Observed prediction of hazard potential.

The results from these two streams were then combined additively to determine the hazard presented by each mode of failure. Hence, a theoretically predicted failure mode which was also observed on site would score significantly higher than one which was not observed.

The RSHI (V1.0) did not follow the theoretical prediction of ravelling as there was no readily available criteria for ravelling failure. Hence, it was decided that a criteria to assess the potential for ravelling failure on a slope should be introduced to a new version of RSHI (V2.0).

From experience of implementing the RSHI in different regions of the UK and with different rock types it became apparent that it would be of assistance to record the most representative value (MRV) for the discontinuity dip and dip direction, rather than just the category (McMillan, 1995). During the course of the current work it was agreed that it would be appropriate to capture data on cases where discontinuities could have low friction angles. Details of these additions to the RSHI are provided in Section H3.1.

H.3 Theoretical Ravelling Criteria

During the development and implementation of the RSHI the project team inspected in excess of 1500 rock slopes and based on this the following ravelling criteria was developed for the rapid assessment of rock slopes.

For the purposes of the RSHI Ravelling can be defined as:

Ravelling – near surface detachment and falling of rock from weak or closely fractured areas of an exposed rock mass. The driving mechanisms include stress relief, physical and chemical weathering, biological activity (e.g. root jacking) and loss of support. The process includes material from mineral grains through gravel (2 - 60mm*) sized and cobble (60 - 200mm*) sized fragments up to boulders (> 200mm*).

*According to the size categories defined in BS 5930:1999.

For the RSHI ravelling was taken as including block fall.

Ravelling failure mode was determined to be significantly controlled by predominantly one or other of the following:

- Presence of areas of rock with a strength of moderately strong or weaker (as defined by BS 5930:1999).
- Discontinuity sets with principal (true) spacings which are moderately closely spaced or closer (as defined by BS 5930:1999).

H.3.1 Additional Data Collection Requirements

To enable implementation of the theoretical ravelling criteria an item was added to the RSHI (V2.0) data collection sheets to enable the determination of the theoretical ravelling criteria based on rock strength. The additional data collection added was:

- % of the rock mass < (less than) moderately strong

This is listed under item 18 on the RSHI (V2.0) data collection forms (see Annex A).

No other additions were required for the theoretical ravelling criteria as the discontinuity spacing data was already captured under item 19 on the RSHI (V1.0 and V2.0) data collection forms (see Annex A).

H.3.2 Rock Strength Criteria

Areas of rock with a strength of Moderately Weak or weaker will tend to be subject to significant weathering and erosion. This leads directly to ravelling of these materials, but also can lead to undermining and loss of support to adjacent rock.

Empirical assessment was used to derive the parameter values for weathering controlled ravelling as shown in Table H1.

Table H1. Rock Strength Controlled Ravelling Criteria Parameters.

% Rock Mass < Mod Strong	Parameter Value	Description
< 10%	Not applicable	Not applicable
≥ 10% and <50%	13	Ravelling on slope starting to be affected by weaker areas of rock mass.
≥ 50% and <70%	18	Ravelling on slope significantly affected by weaker areas of rock mass.
≥ 70%	8	Slope probably dominated by behaviour of weak material and likely to be dominated by mass strength rather than being discontinuity controlled.

H.3.3 Discontinuity Spacing Criteria

To produce blocks of rock a rock mass must be dissected by a minimum of three discontinuity sets, which delimit the blocks. Rock masses which are dissected by two or more medium to closely spaced discontinuity sets are prone to ravelling due to the blocky nature of the resulting rock mass. If the third block delimiting discontinuity set is of greater dimension than the other two then tabular or columnar shaped blocks will result which tend to be either relatively unstable or prone to cracking.

Empirical assessment was used to derive the parameter values for discontinuity spacing controlled ravelling as shown in Table H2.

Table H2. Discontinuity Controlled Ravelling Criteria Parameters.

No. Discontinuity Sets with Principal Spacing < 0.1m or 0.1m to 0.3m	Parameter Value	Description
≥ 2 No.	5	Potential for rock mass to be dissected into blocks by medium to closely spaced discontinuities.
< 2 No.	0	Not applicable.

H.3.4 Implementation of Ravelling Failure Criteria

The derivation of the original RSHI (V1.0) is shown in Figure 5 of McMillan, 2005. The theoretical ravelling criteria sits parallel to the 'Instability Criteria' for plane, wedge and toppling failure, as can be seen in Figures H1 and H2 below. Figure H1 shows the overall RSHI (V2,0) derivation, whilst Figure. H2 shows the detail of the theoretical ravelling criteria.

The only input parameters required for the implementation of the ravelling failure criteria are shown in Table H3 below.

Table H3. Input Parameters for Theoretical Ravelling Criteria.

Parameter	RSHI Data Collection Form (see Appendix A)
% of rock mass less than moderately strong	Item 18 – Rock Weathering
Discontinuity set principal spacings	Item 19 – Discontinuity Set Characteristics
Discontinuity dilation	Item 20 – Average Discontinuity Dilation
Failure Type Observed	Item 21 – Potential Failure Observed on Slope

The resulting theoretical ravelling index value (Figures H1 and H2) is then added to the observed ravelling index value (Figure H1). The resulting combined ravelling index value then follows the same RSHI calculation procedure as the original RSHI.

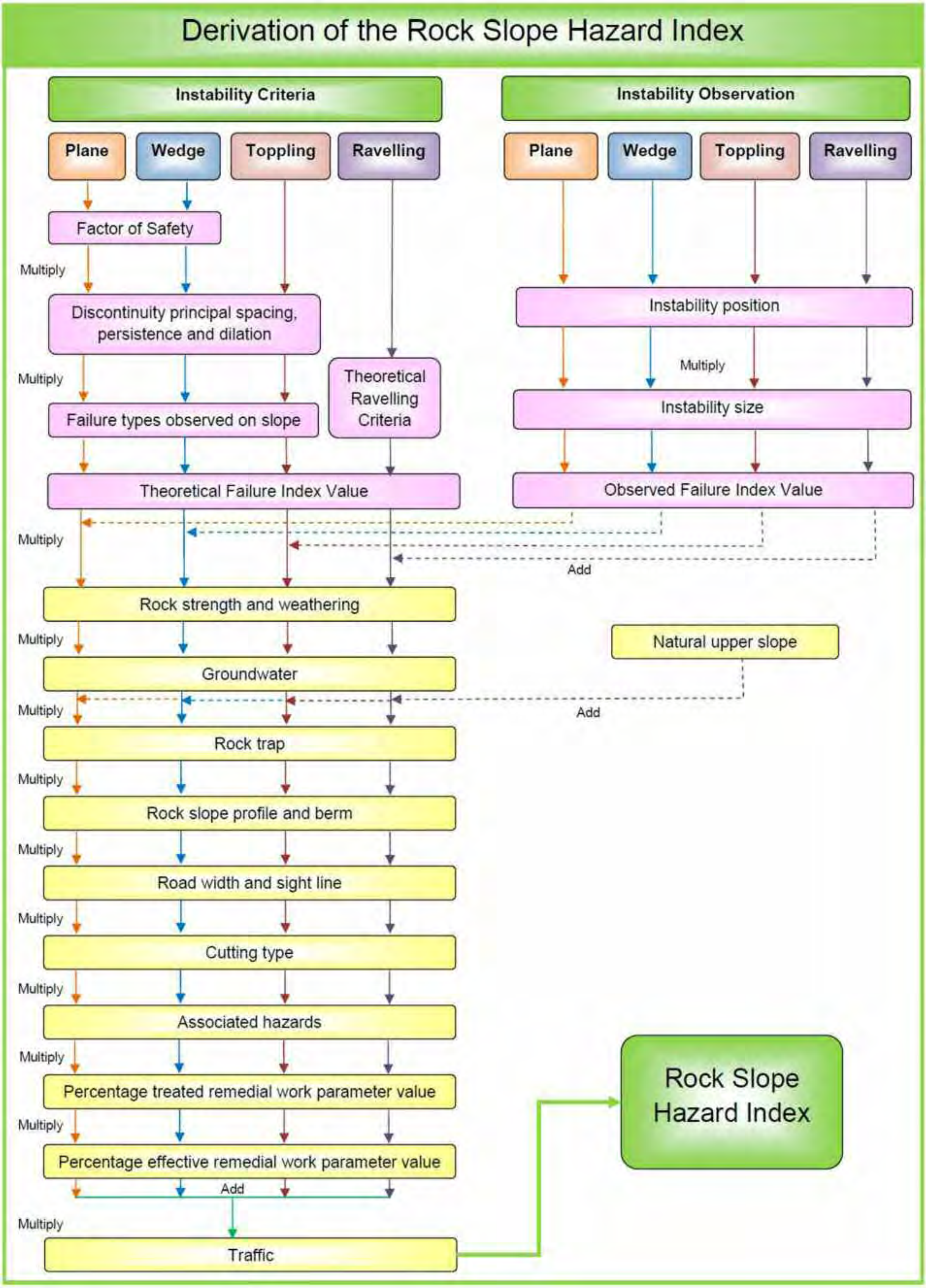


Figure H1. Derivation of the Rock Slope Hazard Index (V2.0).

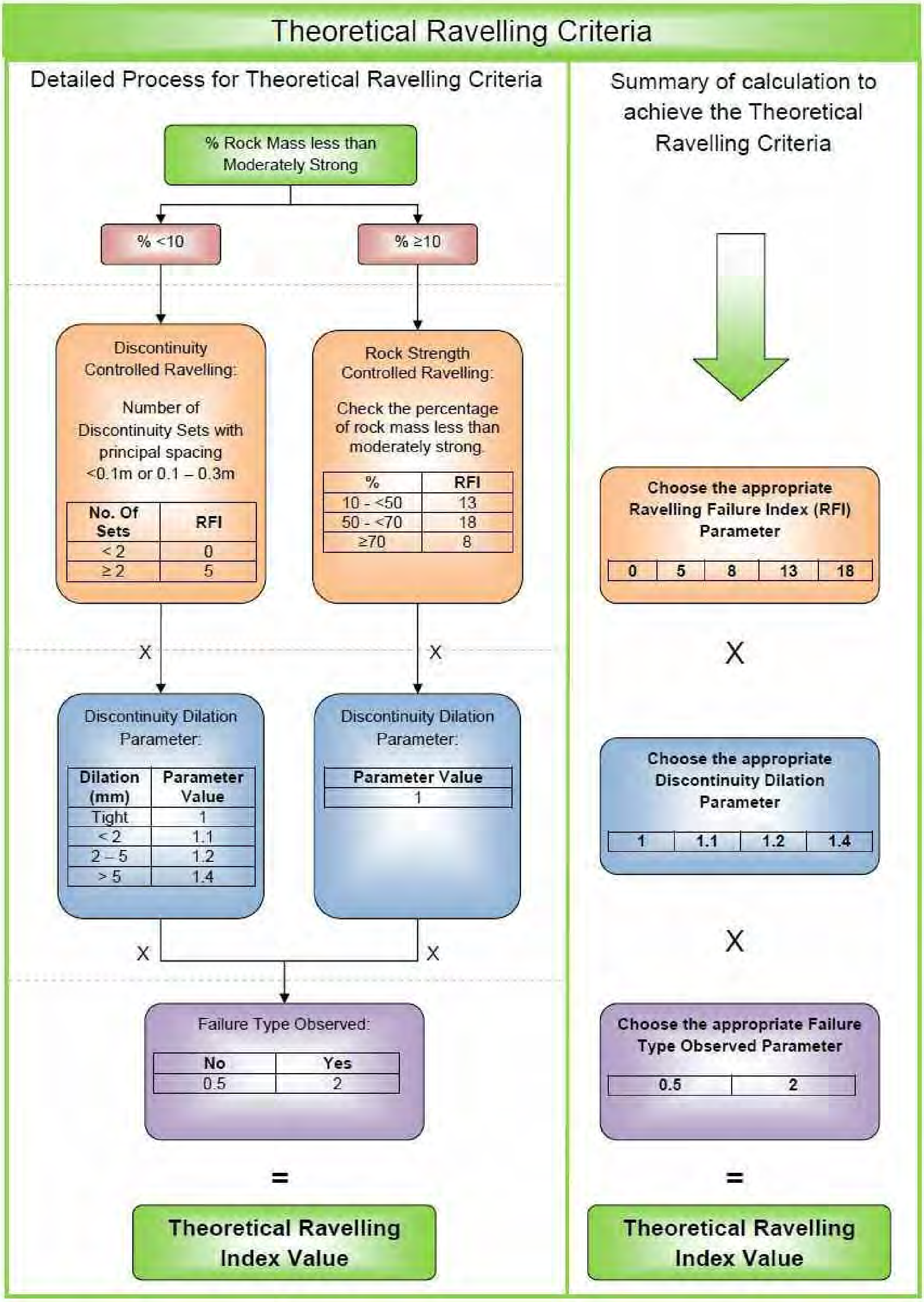


Figure H2. Theoretical Ravelling Criteria Flowchart and Parameters.

H.4 Discontinuity Set Characteristics

As discussed in Section H2 the RSHI (V2.0) requires that additional discontinuity set characteristics are recorded.

Item number 18 on the RSHI (V2.0) data collection sheets (see Annex A) includes the following additions:

H.4.1 Discontinuity Dip and Dip Direction

The RSHI (V2.0) requires the most representative value (MRV) of the dip and dip direction should be determined for each discontinuity set. These MRVs for the dip and dip direction should be entered in the appropriate category boxes.

H.4.2 Low Discontinuity Friction Angle

Should any discontinuity set be identified as potentially having a friction angle of less than 30 degrees, during data collection, then the 'Low Phi Possible' data entry box for that discontinuity set should be marked (see Annex A). Currently this is not used in the calculation procedure, but will be used for checking and quality assurance purposes, and may be utilised in future updates of the system.

Annex A: Rock Slope Hazard Index (V2.0) Data Collection Sheets

Geotechnical Data

Cutting Ref. [ ]

17. Rock Strength

Rock Type [ ]

Weak [ ] Mod. Weak [ ] Mod. Strong [ ] Strong [ ] V. Strong [ ]

18. Rock Weathering

% of rock mass < moderately strong: <10 [ ] 10-50 [ ] 51-70 [ ] >70 [ ]

Fresh [ ] Slight [ ] Moderately [ ] Highly [ ] Completely [ ] Residual [ ]

19. Discontinuity Set Characteristics (average for set)

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Type						
Dip						
<30						
30 - 45						
45 - 70						
70 - 90						
Overturned						
Low Phi Possible						
Azimuth						
+/- 20						
20 - 90 (+or -)						
>90						
Principal Spacing						
<0.1m						
0.1 - 0.3m						
0.3 - 0.6m						
0.6 - 2m						
>2m						
Delimiting Trace Extent						
<1m						
1 - 3m						
3 - 5m						
5 - 10m						
>10m						

20. Average Discontinuity Dilation

Tight [ ] <2mm [ ] 2-5mm [ ] >5mm [ ]

21. Potential Failure Observed on Slope

None [ ]

Position:	Plane	Wedge	Toppling	Ravelling
High				
Medium				
Low				

22. Size of Potential Failures Observed on Slope

Size	Plane	Wedge	Toppling	Ravelling	
$<0.5m^3$				$<0.1m^3$	
$0.5 - 1m^3$				$0.1 - 0.5m^3$	
$1 - 3m^3$				$0.5 - 1m^3$	
$3-6m^3$				$>1m^3$	
$>6m^3$					

Ravelling Shape: Rounded [ ] Sub-Rounded [ ] Angular [ ]

23. Surface Water Flows Cutting Ref. [ ]

None [ ] Minor [ ] Major [ ]

24. Groundwater Seepage

None [ ] Minor [ ] Major [ ]

Remedial Work Data

25. Previous Rock Removal

Scaling		Controlled Removal		Reprofiling	
Light		Explosive			
Heavy		Non-explosive			
% Area		%Area		% Area	
Date		Date		Date	

26. Existing Rock Containment

Netting [ ] Draped [ ] Contoured [ ] Fixed [ ] % Area [ ] Date [ ]

27. Existing Rock Strengthening

Rock Reinforcement

	Monobar Anchors	Multi strand Anchors	Bolts	Dowels
Numbers				
<5				
5-10				
>10				
% Area				
Date				

Support

	Retaining Wall	Buttress	Sprayed concrete	Walling	Strapping
% Area					
Date					

Protection

	Sprayed concrete	Dentition
% Area		
Date		

28. Total % Hazards Treated

	None	<25%	25-50%	51-75%	76-90%	91-99%	100%
Plane							
Wedge							
Toppling							
Ravelling							

29. Effectiveness of Remedial Works

	None	<25%	25-50%	51-75%	76-90%	91-99%	100%
Plane							
Wedge							
Toppling							
Ravelling							

Cutting Ref.

30. Comments/ Sketch

31. Photographs

	From	To
Photo ID		

Logged by		Date	
Input by		Date	
Checked by		Date	

Rock slope risk assessment

The management of rock slopes requires knowledge of their location, traffic levels and other geometric parameters as well as the level of the hazard posed to the road user. This information can then be used to prioritise remedial action. This report details a system that was developed to allow such assessment and prioritisation on the Scottish road network.

Other titles from this subject area

INS001	Improving the stability of slopes using a spaced piling technique. D Carder. 2009
PPR406	Use of intelligent compaction technology. D R Carder, B C J Chaddock (TRL) and L Campton (Halcrow Group Ltd). 2009
PPR341	Drainage of earthworks slopes. D R Carder, G R A Watts, L Campton and S Motley. 2008
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