INTRODUCTION TO RDA

As indicated previously, RDA is divided into three stages:

Stage One: Ratings are applied to four key parameters (Table 1) to obtain a rating for the rock mass. This rating is adjusted (see below) to take account of external factors and excavated slope characteristics. The resulting adjusted RDA_A Class is used to obtain an indication of the general approach that should be taken to slope stabilization and treatment work (Table 2). Adjustment factors are listed in detail in tables A to M below and accompanying charts.

Stage Two: The nature of the deterioration hazard, notably the transport mechanism involved, is assessed qualitatively with reference to the type of rock mass and evidence from slope morphology.

Other documents to refer to: 4. Rock Mass Types, 5. Deterioration Transport Mechanisms, 6. Deterioration Morphology.

Stage Three: The findings of stages one and two are used to obtain guidance on appropriate slope protection and treatment works.

Other documents to refer to: 7. Mitigation Matrix.

RDA STAGE ONE: KEY PARAMETERS

In RDA stage one, two sets of ratings are applied to field data to produce an *RDA Class*. The first set of ratings apply to four key parameters (Table 1), two of which, discontinuity spacing and aperture, relate to rock mass properties, and the other two of which, rock compressive strength and weathering grade, relate to material properties. The rock mass and material properties are weighted equally, giving a maximum *unadjusted RDA Rating* (RDA_U) of 100 (Figures 1, 2 and 3 and Table 3). Ratings are weighted such that higher values equate to an increased susceptibility to deterioration (this is converse to some rock mass classifications where a high value indicates better quality eg Bieniawski 1973, Selby 1980). The ratings and parameter values adopted result from an iterative process in which theoretical, predicted ratings and threshold values were modified and refined on the basis of field observations of actual slope deterioration and measurement of associated parameter values. The RDA_U Rating provides a relative measure of deterioration susceptibility associated with the intrinsic mass and material properties of the excavated rock mass under consideration. In this respect it enables comparison of fundamental geological influences on rockslopes in different rock masses without being complicated by a wide range of external factors.

Fracture spacing (block size)

Collection of data for discontinuity spacing differs from other classifications. Critically, any estimate of spacing should include ALL fractures, whether they form repeated fracture sets or not, and whether they are open or have a tight aperture, though they must be open to some extent (ie with a tensile strength less than that of intact rock). This means that when identifying fractures, those induced by excavation, weathering, rebound or anthropogenic causes should be included alongside bedding planes, joints, faults and other lithological fractures. Incipient or 'hairline' cracks should not be ignored. These so-called 'superficial fissures' (Selby 1980) might have little influence on rock mass strength, but have a very significant influence on deterioration potential (see Nicholson and Nicholson 2000). It is possible to obtain a reasonably accurate measure of discontinuity spacing using standard scanline survey techniques, especially if several are conducted at orthogonal angles. However, this is often not possible. An alternate method, though less accurate, is to estimate the mean block dimension from observations supplemented with short scanlines. The maximum rating which can be allocated for fracture spacing is 35 and this can be determined from Figure 1.

Fracture aperture

Ratings applied to fracture aperture are based on rather different criteria than those for other rock mass classification schemes. For instance, in the RMR (Bieniawski 1973) aperture is incorporated as one element of four defining discontinuity condition. The selection of these elements largely relates to their influence on shear strength of discontinuities, a critical factor in slope stability. In RDA, much greater emphasis is placed on the role of fracture aperture in (i) weathering (allowing root growth, water flow, block wedging, wall weathering and dissolution); (ii) providing potential chutes for material re-distribution; and (iii) contributing to the general 'looseness' of the rock mass. It can be argued that once a fracture is open, its walls are immediately vulnerable to weathering, and therefore subsequently increasing the size of aperture has relatively little impact. It is for this reason that the largest increase in ratings occurs at the narrower end of the scale, and big increases in apertures which are already large, attract little additional numerical weighting. Aperture should be measured in relation to perpendicular separation of fracture walls, regardless of any infilling, unless the fracture is healed. In this case, it should be regarded as intact. The maximum rating which can be given for fracture aperture is 15 and can be determined from Figure 2. The maximum total rating for rock mass properties (fracture spacing and aperture) is 50.

Rock compressive strength

The intact strength of rock is regarded as being of lesser importance in rock mass classifications concerned with slope or tunnel stability than discontinuity spacing (Hack and Price 1993). This can be seen from the RMR system (Bieniawski (1973) in which a maximum of 70 points can be allocated for parameters that relate to discontinuity spacing and condition, with only 15 being allocated for rock strength. In considering deterioration, however, rock strength takes on equal importance since weathering and erosion processes attack rock material as well as the discontinuities contained within it. Although rock compressive strength is a measure of resistance to crushing force, it also closely relates to other rock properties such as texture, density and porosity, and is a reasonable surrogate for rock durability. Rock compressive strength should be estimated from the field-based guide presented in BS 5930 (1999). It can be helpful to obtain Schmidt hammer rebound to refine the field estimate, but this value should not be used as the sole measure of strength. Point load testing can also be undertaken to obtain a more accurate field estimate of compressive strength if portable equipment is available. Samples can be collected to allow for more accurate laboratory testing of strength at a later date. The maximum rating which for rock strength is 35 and can be determined from Figure 3.

Rock material weathering grade

Ratings for weathering grade should be applied on the basis of a qualitative assessment of the weathering condition of the rock material as a whole. Although material weathering might relate to discontinuity walls as much as to the intact rock, it should be based on the latter. The classification system adopted is that produced by the Geological Society Engineering Geology Working Party (1995) to describe uniform materials (Approach 2) and is based on Moye's (1955) attempt to describe granite weathering. It should not be used in the sense of Martin and Hencher (1986) to define the proportion of weathered to unweathered rock, or of Fookes et al (1971) to consider the combined effects of weathering on mass and material properties. The maximum rating which can be given for rock weathering grade is 15 and can be determined from Table 3. The maximum total rating for rock material properties (rock compressive strength and material weathering grade) is 50.

Rock Mass Properties: Maximum total rating = 50	
Fracture spacing (block size) *(maximum rating = 35)*	**Fracture aperture** *(maximum rating = 15)*
Crucially, fracture spacing should include ALL discontinuities deemed to have a tensile strength less than that of the intact rock even if these are incipient *hairline* cracks (e.g. Selby 1980) or *potential weathering lines* (Whalley *et al.* 1982). So, discontinuities induced by excavation, weathering, rebound or other anthropogenic causes should be included along with bedding planes, joints, faults and other lithological fractures. Discontinuity spacing can be determined using orthogonal scanlines or by estimating mean block size from visual assessment.	Fracture aperture is extremely important in weathering, allowing root growth, water flow, block wedging, wall weathering and dissolution, providing chutes for material re-distribution and contributing to the general 'looseness' of the rock mass. The shear strength of fracture walls is much less important in deterioration than for slope instability. Once a fracture is open, any subsequent increase in aperture has relatively little impact. Hence, the largest increase in ratings occurs for narrow apertures. Aperture should be measured in relation to separation of fracture walls regardless of infilling (unless the fracture is healed).
Rock Material Properties: Maximum total rating = 50	
Rock compressive strength (m*aximum rating = 35)*	**Rock material weathering grade** *(maximum rating = 15)*
Intact rock strength is considered much less important in rock mass classifications than discontinuity spacing (e.g. Bieniawski 1973; Hack & Price 1993). However, rock strength is of equal importance in deterioration since weathering processes probably attack rock material as much as the discontinuities contained within it. Rock strength also reflects rock properties such as texture, density and porosity and is a reasonable surrogate for durability. There are a variety of ways to determine or estimate compressive strength in the field and laboratory (e.g. BS 5930:1999).	The assessment of material weathering should be based on the static weathering condition of intact rock, not discontinuity walls. The classification system adopted is that produced by the Geological Society Engineering Geology Working Party (1995) to describe uniform materials (Approach 2) and is based on Moye (1955). Ratings to be applied are as follows: Fresh 0; slightly weathered 5; moderately weathered 10; highly weathered 14; completely weathered 15. Intermediate values can be used as appropriate.

Table 1: Explanation of ratings for four key parameters

RDA_A Class	Adjusted Rating	Deterioration Susceptibility	Approaches to remedial treatment*
1	<21	Very low	**Reactive approach:** Maintain or remedy as necessary. For example infrequent inspection and debris clearance.
2	21-40	Low	**Passive approach:** Control the effects of deterioration by containment and protection. Examples include scaling; wire netting; rock catch ditch and protective fencing.
3	41-60	Moderate	**Active approach:** Reinforce the slope and slope materials to resist processes of deterioration. For example surface protection (e.g. shotcrete, geotextiles and vegetation); dowels, cables, anchors and rockbolts; dentition.
4	61-80	High	**Intrusive approach:** Retain and support the slope. Examples include crib walls, gabions and buttresses; underpinning.
5	>80	Very high	**Slope re-design:** Examples include reducing slope gradient; benching; increasing stand-off; rockfall shelters.
* Approaches to remedial treatment are cumulative, i.e. a class 3 slope will require an 'active' approach *in addition* to measures indicated for classes 1 and 2.			

Table 2: General approaches to treatment of deteriorating rockslopes

When applying ratings to properties, due consideration should be given to any stabilisation measures already in place. For example, if multiple blocks are effectively behaving as a single block because of existing rockbolt reinforcement, discontinuity spacing should be reduced accordingly, or where fractures have been sealed, discontinuity aperture should be regarded as zero. Where the surface of the rock has been covered (e.g. by shotcrete) the rock should be classified as unweathered and intact. Where mitigation measures merely provide a protective function (e.g. netting, rocktrap ditch), values for key parameters should be determined in the normal way.

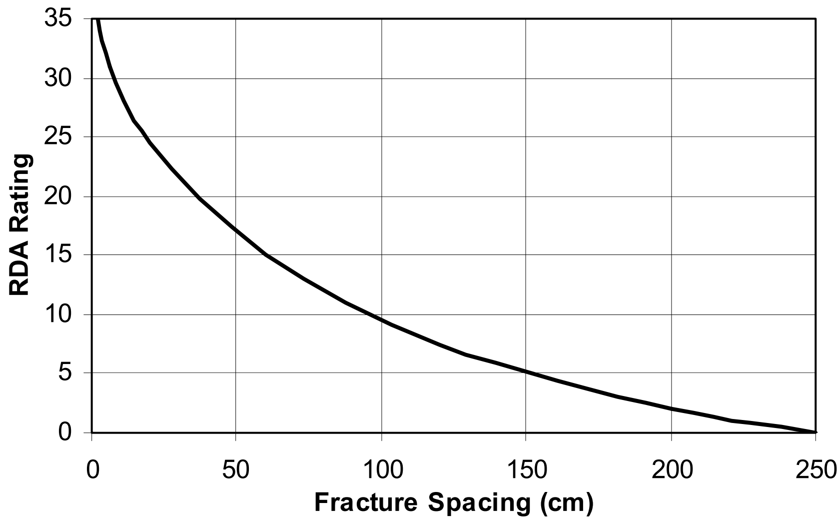


Figure 1: RDA rating curve for fracture spacing

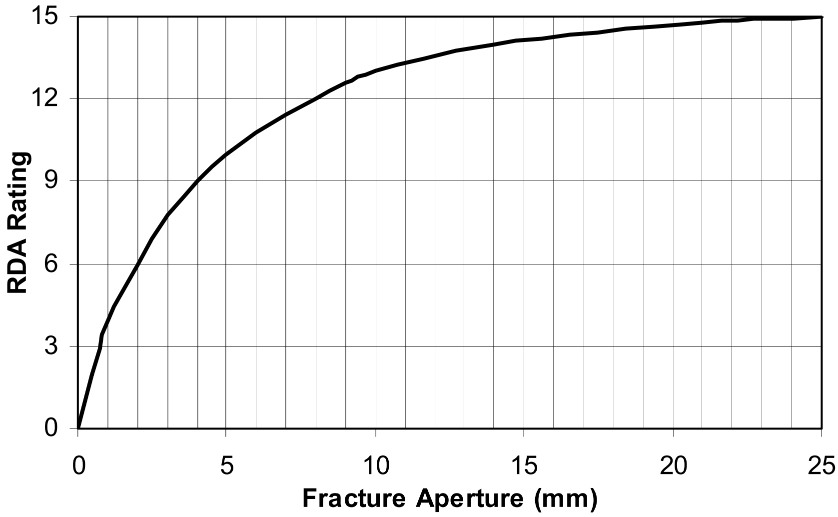


Figure 2: RDA rating curve for fracture aperture

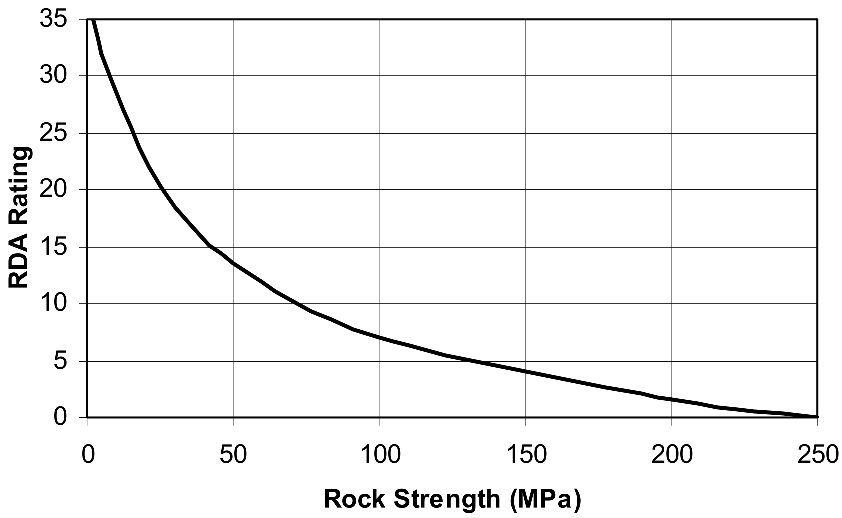


Figure 3: RDA rating curve for rock strength

Grade	**Material description**	**Rating**
Fresh	Unchanged from original state.	0
Slightly weathered	Slightly discoloured; slight weakening.	5
Moderately weathered	Weakened in association with penetrative discolouration.	10
Highly weathered	Large pieces (eg NX drill core) cannot be broken by hand; does not readily slake when imersed.	14
Completely weathered	Considerably weakened; slakes readily; original texture retained.	15
Residual soil	No original fabric or texture remains (soil).	n/a

Table 3: RDA ratings for weathering grade (based on Geological Society Engineering Geology Working Party, 1995 Approach 2, also based on Moye, 1955)

RDA STAGE ONE: ADJUSTMENT FACTORS

The second set of ratings are adjustments made on the basis of the potential impact of external conditions including environmental conditions, stress conditions, engineering factors and excavated slope characteristics. The RDA Rating adjustments serve two primary purposes, first, to adjust the RDA_U Rating to reflect deterioration susceptibility based on actual site factors, and second, to draw attention to particular factors which influence deterioration behaviour. The ratings for these adjustments vary from -10 to +13, in recognition of the fact that some influences increase deterioration susceptibility (positive values) while others reduce deterioration susceptibility (negative values). Most of the adjustments are given as ranges. This is deliberate, to allow for engineering judgement to respond to local conditions. As a general guide, a small number of adjustments will apply for most rockslopes. A typical total adjustment lies in the range -5 to +15 (Nicholson 2003), but could, in rare circumstances, be as much as -25 or +25 (i.e. more than one RDA Class).

The underlying principle in applying adjustments is that they are applied to conditions affecting *non-standard rockslopes*. A 'standard' rockslope is regarded as an existing slope situated in a protected, low altitude location in a marine temperate climate (e.g. United Kingdom). It is not subject to any significant dynamic or unusual static stresses and is up to 15m in height. The slope is dry, has no vegetation cover or remedial works and is not subject to any direct disturbance. The slope has been recently excavated (e.g. up to one year) and its physical structure neatly fits into one of seven rock mass types (identified in RDA stage two).

Most adjustments apply both to existing rockslopes and to proposed slopes (i.e. those being assessed from intrusive in investigation and/or surface exposures *prior* to excavation). However, some adjustments apply only to proposed rockslopes (e.g. deep excavations, D1 and excavation method, F) while others apply only to existing rockslopes (e.g. stabilisation and protective measures, G1 and slope geometry, J2.a and J2.b). For each sub-group, no more than one adjustment should be used for each group of similarly numbered items.

The adjusted RDA Rating (RDA_A) is found as follows:

$RDA_A = RDA_U + \text{Total adjustment}$

Where $RDA_U = \sum \{\text{Fracture spacing + aperture + rock strength + weathering grade}\}$

and

$\text{Total adjustment} = \sum \{A + B + C + D + F + G + H + J + K + L + M\}$

Theoretically, the RDA_A Rating could lie outside the range 0 to 100 but in practice this is extremely unlikely. RDA was applied to over 200 slope units and comparison with field observations and documentary evidence indicates that the weightings work well and are a good reflection of actual deterioration. The RDA_A Rating is divided into five RDA Classes with boundaries evenly distributed between 0 and 100. Class 1 ($RDA_A \leq 20$) represents rockslopes with a very low susceptibility to deterioration and

Class 5 (RDA_A > 80) represents rockslopes with a very high susceptibility to deterioration.

Once the RDA_A Rating has been determined, reference can be made to Table 4 to gain an indication of general approaches to mitigation for each class. This guidance is useful for feasibility planning is not intended to provide a basis for detailed planning of mitigation and protective measures. Observations made during the research indicate that successful mitigation needs to be based on a good understanding of the nature of the deterioration hazard.

Deterioration of rockslopes can be mitigated using a variety of approaches. Slope treatment can be *reactive*, that is, works are carried out in response to infrequent or minor deterioration of a slope. A *passive* approach can be adopted, where the effects of deterioration are reduced by containment (e.g. rocktrap ditch and fencing) and protection (e.g. barrier). An *active* approach can be adopted where the quality of materials forming the slope is either improved or reinforced (e.g. shotcrete, dentition and rockbolting). An *intrusive* approach can be adopted where substantial slope support, buttressing and retention are introduced (e.g. retaining walls and underpinning). If it is accepted that deterioration has too much damage potential to be treated or mitigated successfully, major *slope re-design* can be undertaken (e.g. modify geometry, increase standoff). In all of these approaches it is probable that drainage measures will form a part of the overall solution.

The Adjustment Factor Tables and Charts

ENVIRONMENTAL FACTORS

A	**Altitude, Exposure** (see Table A1) **and Climatic Conditions**	
1.a	High altitude (>300m) localities (add 4 for >400m).	Up to 4
1.b	High altitude localities or coastal locations which are also slightly, moderately or very exposed (affected by *driving* wind and rain).	2 to 7
1.c	Moderately or very exposed, moderate altitude (150 to 300m) localities.	1 to 3
1.d	Moderately or very exposed, low altitude (<150m) localities.	1 to 3
2.a	Frost or moisture pockets and sites of cold air drainage. *Apply only to slopes which are very sheltered and enclosed. Use a greater adjustment for high slopes (eg >12m).*	1 to 4
2.b	Sun traps. *Apply only to low (eg <8m high), south or south west facing slopes which are sheltered or slightly exposed, and which are never shaded (eg by trees or structures). Use a higher adjustment for shallow gradient slopes or where the rock is rich in clays.*	Up to 3

Table A: Altitude, exposure and climatic conditions

Sheltered	For example, a two-lane highway with excavated rockslopes on each side, notwithstanding any other extremes of altitude or climatic conditions. Alternatively, a continuous, multiple layered belt of evergreen trees located opposite the rockslope, reaching to at least the height of the slope and densely underplanted with evergreen shrubs. The distance between the shelterbelt and the slope would need to be less than twice the height of the slope. A discontinuous, or single layered, or deciduous tree belt provides less shelter. A slot-like quarry location or surrounding higher relief in close proximity also provide considerable shelter.
Slightly Exposed	For example, a medium sized quarry enclosed on all sides. 'Medium sized' depends on the length and breadth of the quarry, and also on the relationship of these dimensions to its depth. A dual carriageway with cuttings on either side is another example.
Moderately Exposed	For example, a very large quarry with no shelter provided by its basin-like form. A motorway crossing open land which passes through cuttings would be another example, as are slopes which face onto land which is open for up to 1km away.
Very Exposed	For example, slopes situated on topographic highs at higher altitudes overlooking land which falls away into the distance, with no shelter provided and completely exposed to the elements. Individual units of a such slopes which were locally protected by close proximity vegetation, structures or other slopes might be classed only as moderately exposed.

Table A1: Definition of exposure levels used in Table A

Adjustment A1: Exposure levels are defined in Table A1. Altitude can be obtained from topographic maps. For A1.a it is recommended that an adjustment of 3 be applied to slopes approaching 400m and the maximum adjustment be applied for slopes at significantly higher altitudes. For A1.b the adjustment should be based on the combined effects of altitude and exposure conditions.

Adjustment A2.a: Frost or moisture pockets are characterised by being permanently or semi-permanently cast in shade such that the rock rarely, if ever, dries out. This condition is likeliest for north facing slopes, in deep hollows, or in shallow hollows with a dense vegetation cover. Cold air drainage occurs where local conditions funnel and pond cold air draining from exposed slopes above, and is commonly found where tunnels, caves or mine entrances are present at a low level in or near the slope.

Adjustment A2.b: A sun trap is a slope situated in a sheltered environment which rarely receives the full force of wind and rain. It is also south facing and largely free from vegetation so that it receives maximum solar radiation. Shallower gradient slopes receive greater solar radiation intensity because of the angle of incidence of the sun. The primary effect of a sun trap is to produce rapid drying out of slope materials which can lead to drought. This can kill off vegetation periodically, which then collapses, taking slope materials with it. In clay-rich materials, it can also lead to desiccation cracking. The most serious deterioration effects occur if meteorological conditions are such that rapid and repeated wetting and drying occurs, especially in clay-rich rock.

B	**Aspect**	
An aspect adjustment should not be applied for sheltered slopes, or for slopes where microclimatic behaviour is dominated by the position of the slope in a frost pocket or sun trap (adjustments A2.a and A2.b). Where an intermediate bearing applies, use an intermediate adjustment.		
1.a	Northerly or westerly aspect *(apply the higher adjustment where there is widespread evidence of rock moisture retention such as moss, algae, surface staining or where there is evidence of drought).*	2 to 4
1.b	Easterly to southerly aspect *(apply a higher adjustment for slopes with vegetation cover)*.	0 or 1

Table B: Aspect

Adjustment B1: Since aspect is indirectly incorporated into adjustments A2.a and A2.b, no duplication of ratings should occur. Where several slope aspects are represented, determine RDA Class separately for each, or use an intermediate rating. An adjustment of at least 1 should generally be applied for south westerly aspects.

C	Groundwater and Surface Runoff	
Apply a lower adjustment where flow is very localized and a higher value if widespread. Apply the adjustment for the worst case. If contrasting volumes of flow are present in different areas of the slope, either (i) use an intermediate adjustment, or (ii) conduct a separate RDA evaluation. Note that flow need not be due to natural hydrological processes, but can be induced by failed slope drains or moisture retention due to artificial surface cover (eg masonry). In each case, conditions might be real or inferred from evidence. Refer to note in H.		
1.a	Rock surface dry, no evidence of seepage or very localized surface dampness.	0 to 1
1.b	Localized slow dripping or moderate areas of damp or wet rock.	1 to 2
1.c	Steady dripping, light continuous flow or large areas of wet rock surface.	1 to 4
1.d	Moderate, continuous flow.	3 to 7
1.e	Excessive, continuous, strong flow.	4 to 9

Table C: Groundwater and surface runoff

Adjustment C1: It is recognised that direct evidence of groundwater seepage and surface runoff might not be available during dry periods, but *circumstantial evidence* of these can be gathered in the form of process indicators (see separate .pdf document on deterioration morphology).

STRESS CONDITIONS

D	Static Stress	
1	Deep excavations (eg where overburden depth removed >20m) in strong, massive rock. *This adjustment should be ignored for EXISTING rockslopes. Apply the maximum adjustment for very deep excavations (>50m).*	Up to 3
2	Surcharge at the slope crest (eg structures, trees). *Refer to note in H3c.*	Up to 2

Table D: Stress conditions

Adjustment D1: The potential for stress release is much less in existing rockslopes since elastic rebound will have occurred at the time of excavation. Non-recoverable rebound will occur time dependently in response to weathering. This adjustment, therefore, only applies to proposed rockslopes.

Adjustment D2: In the context of excavated rockslopes, surcharge due to loading at the crest is uncommon, and is most likely to relate to normal stresses produced from mature trees.

E	**Dynamic Stress**	
1.a	Dynamic loading due to quarry blasting in close proximity (up to 100m) to the slope. *Apply a higher adjustment for long term, high frequency blasting.*	1 to 3
1.b	Ground vibration due to traffic movement on high speed roads in very close proximity (up to 10m) to the slope. *Apply the maximum adjustment for roads with a high proportion (>10%) of heavy vehicles AND poor road surface condition (eg rough, irregular, potholes and infilled trenches). Apply a lower adjustment where only one of these apply and no adjustment where neither apply.*	2 to 4

Table E: Dynamic stress

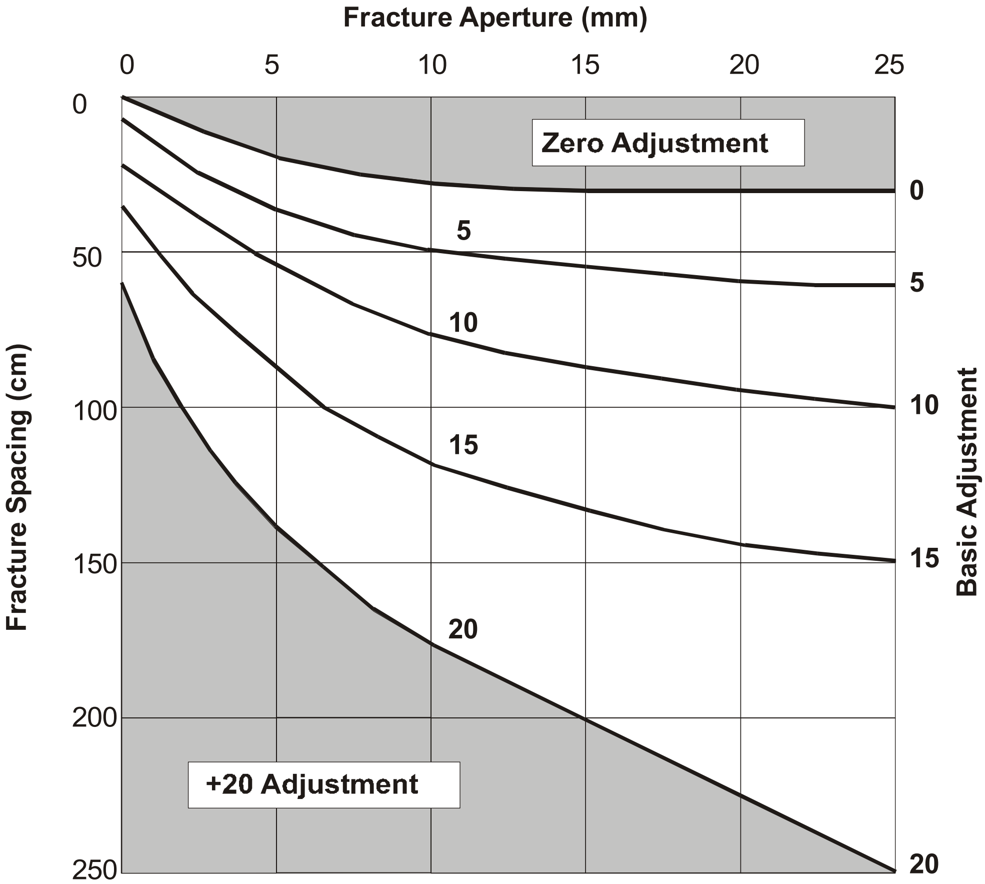
Adjustment E1: These adjustments are closely related to land use. E1.a is most likely for disused slopes within active quarries, although road cuttings or disused quarries in close proximity to active workings might also be affected. E1.b clearly relates to high speed roads such as motorways, dual carriageways, and some single carriageways in national (ie maximum) speed limit zones.

ENGINEERING FACTORS

F	**Excavation Method** (Figure F1)
	Excavation method adjustments should be ignored for EXISTING rockslopes. For PROPOSED rockslopes, obtain an adjustment from the "RDA Rating adjustment for excavation method" (Figure F1).

Table F: Excavation method

Figure F1: RDA_U Rating adjustment for excavation method (proposed slopes only)



EXCAVATION METHOD ADJUSTMENT FACTORS

1. For BULK (quarry) BLASTING add x0.8 to x1.0 of basic adjustment
2. For SMOOTH BLASTING add x0.3 to x0.6 of basic adjustment
3. For PRE-SPLIT BLASTING add x0.0 to x0.2 of basic adjustment
4. For MECHANICAL EXCAVATION add x0.0 to x0.1 of basic adjustment
5. For HAND EXCAVATION *subtract* x0.2 to 0.0 of basic adjustment

Adjustment F: For existing rockslopes, any deleterious effect of excavation method will already have contributed to fracture spacing and aperture and there is no need to apply any adjustment. Adjustments should only be made for proposed slopes. The adjustments given in Figure F1 are based on two fundamental assumptions: (i) that some excavation methods have a much greater deleterious effect on rock mass quality than others, and (ii) that rock mass properties determine the effect of each excavation method. For example, the effects of bulk blasting (eg increases in fracture intensity and aperture) will be much more evident in a rock mass with few, tightly closed fractures, than in a highly jointed rock mass, where much of the blast energy will be dissipated via the existing fracture network.

Worked example: For a rockslope with a fracture spacing of 60cm and an aperture of 2mm, the basic adjustment from the chart would be +13. If the rock mass were to be excavated by bulk blasting, the *actual* adjustment to be added to RDA_U would be 13 x 0.9 = 11.7. If pre-splitting were used, the *actual* adjustment would be 13 x 0.2 = 2.6, and if hand excavation were used, 2.6 points would have to be subtracted from RDA_U. Some flexibility is given in the excavation method factors to allow for varying quality of blast design (eg hole spacing and charge weight), machinery and tools.

G	**Stabilisation and Protective Measures**	
1	Deterioration associated with EXISTING stabilisation measures (eg material weathering around rockbolt heads; spalling associated with drainholes, rockbolts and dowels). *Apply a low adjustment unless a widespread effect.*	Up to 3

Table G: Stabilisation and protective measures

Adjustment G1: Occasionally, stabilisation measures exacerbate deterioration locally and the purpose of this adjustment is to allow for this to be accounted for in the RDA Rating.

EXCAVATED SLOPE CHARACTERISTICS

H	**Vegetation Cover**	
Care should be taken in H1a and H3a not to duplicate adjustments already made in C for surface moisture retention (eg by moss and algae) and its potential weathering effects.		
Highly weathered or soil-like slopes (excluding highly fractured rockslopes)		
1.a	Cover of grass or other fine-rooted, low-growing, herbaceous plants. *Apply a maximum adjustment for widespread, dense, well established cover, an intermediate adjustment for moderate coverage of medium density vegetation, and a minimum adjustment for sporadic, thin or newly established cover.*	-10 to -2
1.b	Small woody shrubs and trees (up to 3m height). *Apply a high negative adjustment for widespread, dense cover and a low adjustment for isolated occurrences with only localised effect.*	-6 to 0
1.c	Widespread, dense cover of large woody shrubs and trees (exceeding 3m height). *Apply a high negative adjustment for vegetation up to 5m height and a low adjustment where this height is exceeded.*	-4 to -2
Where more than one adjustment applies in 1, use the largest relevant adjustment ONLY.		
2	Isolated growth of large woody shrubs and trees (exceeding 3m height). *Apply a low adjustment for vegetation up to 5m height and a higher adjustment where this height is exceeded.*	0 to 2
Slopes cut in rock (including highly fractured rockslopes)		
3.a	Cover of grass or other fine-rooted, low-growing herbaceous plants. *Use a low adjustment where growth is sporadic and a high adjustment for widespread cover or where substantial soil has accumulated.*	0 to 3

3.b	Small woody shrubs and trees (up to 3m height). *Apply a low adjustment for isolated occurrences with only localised effect and a high adjustment for more widespread cover or where substantial soil has accumulated.*	1 to 5
3.c	Large woody shrubs and trees (exceeding 3m height). *Apply a low adjustment for isolated occurrences with only localised effect and a high adjustment where there is more widespread cover, or substantial soil accumulation, or large stem diameter (greater than 20cm), or isolated occurrence with widespread effect. Where an adjustment was made for surcharge due to trees at the slope crest, the total adjustment for D2 and H3c should not exceed 8.*	2 to 7
Where more than one adjustment applies in 3, use the largest relevant adjustment ONLY.		

Table H: Excavated slope characteristics

Adjustment H: The underlying principles for vegetation cover adjustment are that (i) root growth in very weak and soil-like materials is likely to have a beneficial, reinforcing effect. This will be enhanced with widespread vegetation cover, particularly for grasses, herbaceous plants and low-lying shrubs. Growth of very large woody plants can lead to disruption due to windloading. (ii) Vegetation growth in stronger materials is likely to have a deleterious effect. This will be increased with widespread vegetation cover, particularly for taller plants and the more penetrative root systems of shrubs and trees.

For each of the conditions presented here a wide range of ratings is offered. This reflects the variety of vegetation effects depending on plant species; rooting depth and spread; age; nutrient availability; and moisture and temperature regime.

J	**Slope Geometry**	
1.a	Slopes (or individual risers in benched excavations) with a height greater than 15m. *Apply the maximum adjustment for slopes exceeding 30m in height. The total adjustment from items D1 and J1 should not exceed 5.*	2 to 5
1.b	Slopes wholly or partly comprised of benches less than 1.5m in height. *Only apply where total slope height is <15m and overall slope gradient is <60^{o}.*	-2 to –5
1.c	Slopes with a total height less than 4m.	-2 to –3
2.a	Uniform, planar surface with little irregularity or large scale roughness in highly weathered or soil-like materials. *Apply only to EXISTING slopes.*	Up to 3
2.b	Uniform, planar surface with little irregularity or large scale roughness on slopes cut in rock. *Apply only to EXISTING slopes.*	-3 to 0

Table J: Slope geometry

Adjustment J1: Where rockslopes contain several benches, each can be treated separately. However, some adjustments need to be made with respect to the slope as a whole (eg static stress and surcharge).

Adjustment J2: A uniform, planar slope profile will increase the velocity of surface runoff, and in very weak materials this can lead to wash erosion. In stronger rocks, undermining, overhang collapses, toppling and the like are less common on planar slopes.

K	**Rock Mass Structure** (Figure K1)	
	For rock masses with extremely poor material properties (eg highly weathered and weak) but excellent mass properties (eg essentially structureless) and vice versa (eg an intensely fractured and loose rock mass in strong, fresh rock), and where the RDA_U Rating for the two unfavourable parameters is >35, the total RDA_U Rating must be adjusted as in item 1. The adjustment to be applied can be determined from the chart given in Figure K1 (it can also be calculated using the percentage figures given in 1.a, 1.b and 2.c below).	
1.a	Where the RDA_U Rating for the two favourable parameters is 0-10% of the rating for the two unfavourable parameters.	13
1.b	Where the RDA_U Rating for the two favourable parameters is 10-20% of the rating for the two unfavourable parameters.	9
1.c	Where the RDA_U Rating for the two favourable parameters is 20-30% of the rating for the two unfavourable parameters.	5
2.a	A single, dominant set of regular fractures (eg bedding planes or joints) such that there are very few discontinuity intersections and a regular structure.	-1 to -7
2.b	Rock mass dominated by angular, blocky shapes with at least one acute angle (eg highly interlocking).	-3 to 0
3	Highly variable or composite rock mass containing discrete zones of contrasting rock mass and/or material properties (eg highly fractured areas, shear zones) which cannot be evaluated separately. *Use a **positive** adjustment where ratings for mass and material properties have been based on the most favourable zones, and a **negative** adjustment where they have been based on the least favourable zones (eg intensely fractured zones).*	0 to 7 OR -7 to 0
4	Favourability of dip angle and direction for recurring fracture sets (favourable = 0; unfavourable = 1-3; very unfavourable = 3-6). *For small blocks (eg <300mm) use lower end of range given, and for large block sizes (eg >600mm) use higher adjustment. Favourability refers to deterioration failures NOT deep-seated slope instability.*	Up to 6

Table K: Rock mass structure

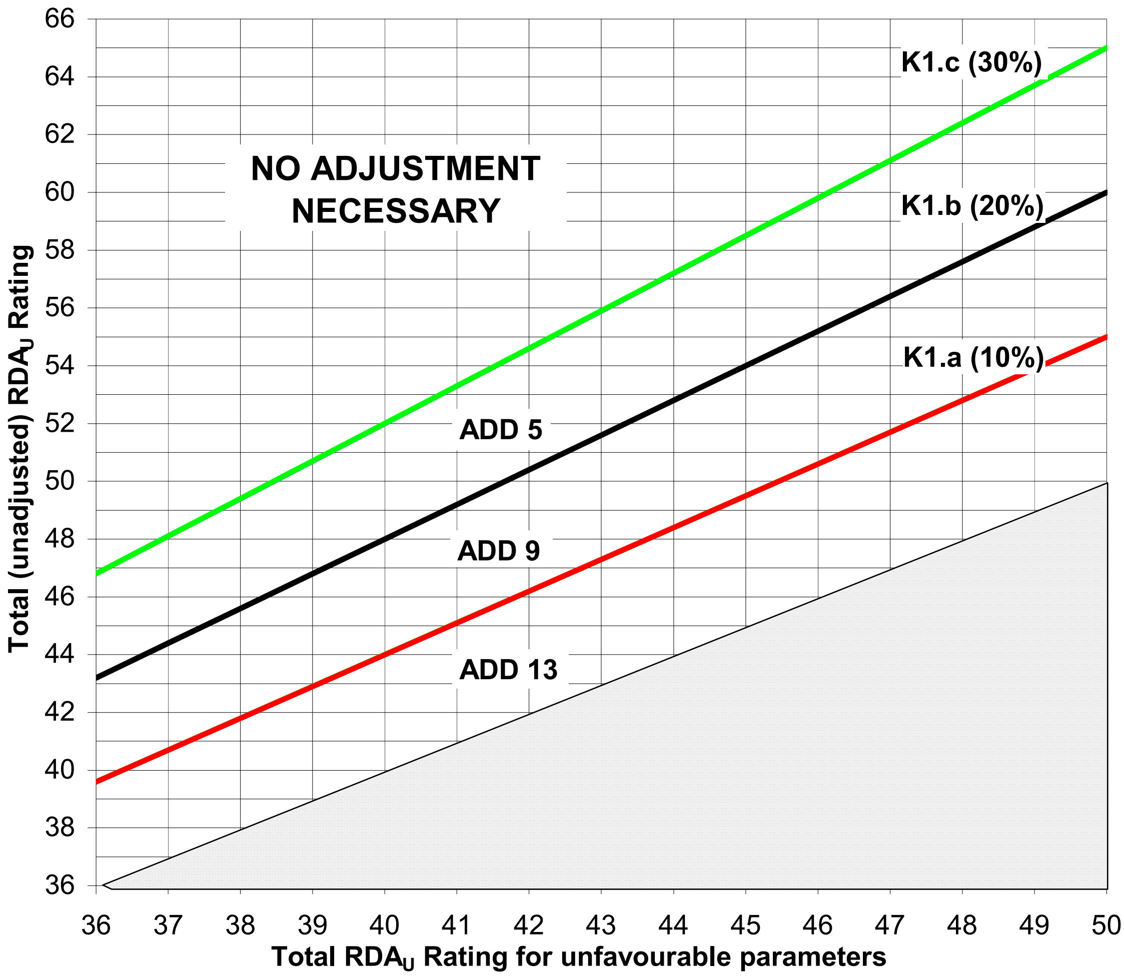


Figure K1: Adjustment chart for use with RDA Rating adjustment K1a, b and c

Adjustment K1: It is possible to envisage a situation in which a rock is so weak and weathered, that in terms of the potential influence on deterioration, the presence or absence of fractures and their apertures becomes largely irrelevant. The reverse situation can also occur, where a rock mass is so intensely fractured, with wide apertures, that the fact that the material is strong and fresh, is irrelevant. In either case, it is possible for the RDA_U Rating to be around 50, giving an RDA_U Class of 3. This would not be a good reflection of the high risk of deterioration for that rockslope and so the adjustments given in K1.a to K1.c should be used. A chart (Figure K1) is used to determine the adjustment that should be applied.

Worked example: A rockslope has an RDA_U Rating of 55. This is made up of a mass rating (fracture spacing and aperture) of 47 and a material rating (rock strength and weathering grade) of 8. The fact that the rating for the two unfavourable parameters (ie the mass properties) exceeds 35 means that adjustment K1 is applicable. The chart given in Figure K1 can then be used to determine how much adjustment to make to RDA_U. Using the chart in Figure K1, the total unadjusted RDA_U Rating of 55 is selected on the y axis. This line is followed to the right until it intersects the x axis value relating to the total RDA_U Rating for the *unfavourable parameters*, which is 47 in this example. The intersection lies in the zone in which an adjustment of +9 should be made to the RDA_U Rating. This zone represents situations where the rating for the two *favourable parameters* (8 in this case) is between 10 and 20% of the rating for the two *unfavourable parameters* (47 in this case) and is described in section K1.b of adjustment K1. K1.a deals with situations where the respective percentage is <10%, and K1.c where the respective percentage is 20 to 30%.

Adjustment K2.a: In a layered rock mass in which the discontinuity causing the layering is extremely persistent and there are very few cross-cutting fractures, it can be difficult to determine block size. For thick layers (eg >1m), it is legitimate to calculate the *mean* block length. Since this is effectively infinite the maximum block size (2.5m) can be used. However, this is less acceptable for thinner layers since they are more vulnerable to weathering and erosion. In this case, the *layer thickness* should be used for block size. This will under-estimate actual mean block size and so the negative adjustment is applied. A larger adjustment should be used for thinner layers.

Adjustment K2.b: It has been observed that highly fractured rock masses remain relatively stable where blocks are tightly interlocked. This is common in igneous rockslopes, but can also be found in crystalline limestones (eg Gagen 1988).

Adjustment K3: As indicated, rockslopes should be divided into zones of similar character before applying RDA. However, identification of distinct zones might be very difficult in highly variable rock masses with contrasting properties in close proximity to each other. In these cases, apply rating adjustment K3.

Adjustment K4: Discontinuity dip and direction are an important component of factor of safety equations for deep-seated instability. However, other rock mass properties such as block size and degree of interlocking, and various climatic and process-related trigger factors assume much greater importance in the context of deterioration. Nevertheless, the favourability of dip and direction influences the behaviour of individual large blocks subject to deterioration. A small adjustment for the favourability of dip and dip direction is therefore made available. Favourability must be judged on the basis of the kinematic relationship between the block under investigation and the slope geometry.

OTHER FACTORS

L	**Time Since Excavation**	
1.a	All natural slopes, and slopes excavated more than 80 years ago. *Only adjust for natural slopes where there is no active erosion (eg by basal undercutting).*	-10 to -8
1.b	Slopes excavated between 50 and 80 years ago.	-8 to -5
1.c	Slopes 30-50 years.	-4 to -1
1.d	Pre-split blasted or slopes excavated mechanically 5 to 30 years ago.	-5 to -2
1.e	Pre-split blasted or slopes excavated mechanically in the last 5 years.	-2 to 0

Table L: Time since excavation

Adjustment L1: The premise of this adjustment is that the severity of deterioration decreases with time since excavation, as slopes achieve equilibrium with their geological environment. Increased stability can also be achieved at an earlier stage if pre-split blasting or mechanical excavation methods are used.

M	**Direct Disturbance**	
1	Anthropogenic disturbance (eg walking, climbing, grazing, fossil collecting).	1 to 3
2	Basal undercutting (eg marine action; river erosion; weathering, collapse or erosion of underlying rock). *Use a higher adjustment if undercutting is rapid, or where there is evidence of collapse of overlying rock as a direct consequence.*	1 to 6

Table M: Direct disturbance

Adjustment M1: Normally, human or animal disturbance of a rockslope is only likely to have a very localised influence on deterioration, but the range of ratings provided allows for unusual situations to be considered.

Adjustment M2: Basal undercutting, while a common process affecting natural sea cliffs and river banks, is rare for excavated rockslopes. One situation in which it does occur, however, is where substantial undermining of more competent rocks occurs due to weathering and erosion of underlying weak material.

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