APPLICATION AND VERIFICATION OF RDA

1. Selected Rockslope Deterioration Assessments

In this section, three worked examples of RDA are presented. The first is a weak massive rockslope in sandstone, the second is an irregular blocky rockslope in ignimbrite, and the third is a fissile and layered rockslope in metasediment.

1.2 Bongate Scar: Weak massive rockslope

Bongate Scar is a very old, hand excavated quarry situated at the edge of the floodplain of the River Eden in Cumbria at grid reference NY 687199 (Plate 1). The rock is a medium grained, uncemented, friable, slightly weathered, weak SANDSTONE with characteristic red coloration due to haematite coating of grains. The rocks are part of the Penrith Sandstone formation of Permian age. The structure consists of very large scale dune cross bedding with occasional vertical joints. The slope is mostly uniform, but contains some very localised intensely fractured zones. For clarity, the latter are not considered in the RDA presented.

Plate 1 General view of Bongate Scar

1.2.1 Stage One RDA

The unadjusted RDA_U Rating for the slope is 41 and was calculated as follows:

Key parameter	Value	Rating
Fracture spacing	>250cm	0
Fracture aperture	2mm	6
Rock strength	4MPa	32
Material weathering grade	Fresh to slightly weathered	3
Unadjusted RDA Rating (RDA_U)		**41**

Table 1 *Calculation of RDA_U for Bongate Scar*

On this basis, this slope is classed as being on the borderline between low to moderate risk (class 2/3). Adjustment factors were calculated on the basis of the following information:

Environmental conditions: The slope is located at an altitude of 145m AOD. It has a west to north west aspect and is situated in an extremely sheltered valley bottom environment, surrounded by mature trees. The slope therefore receives little direct sunlight and appears to remain damp for much of the time. A widespread cover of moss and algae on parts of the rock surface is further evidence of this. There is no seepage present but waterflow exists in the form of closely spaced laminations being picked out by wash erosion (Plate 2).

Plate 2 Evidence of water flow

Stress conditions: There are several large, mature trees at the edge of the crest of the slope, some of which overhang. The slope is located behind a church in a small village and is not subject to any dynamic stresses from blasting or traffic vibration.

Engineering factors: There is no evidence of any engineering intervention.

Excavated slope characteristics: Apart from the moss and algae already mentioned, the only vegetation *on* the slope face are one or two mature trees which have managed to grow successfully in the widely spaced vertical joints. There is some small scale fragmentation associated with these. The slope reaches a maximum height of 15m but is more typically 12m, and has been cut to a gradient of 85 to 88^{o}. The slope comprises a single lift and is quite planar. Most of the adjustments for rock mass structure do not apply, since the RDA_U does not satisfy the conditions for adjustment K1 (where the total rating for rock mass or rock material properties must be >35), and the rock mass is massive and uniform. The only open fractures present are vertical joints, and so there is no intersection of fractures.

Other adjustments: The quarry has not been excavated for at least 80 years and was cut by hand. Cattle and sheep graze on the floodplain at the foot of the slope but are unlikely to cause any disturbance. There is no evidence to suggest that the slope has been flooded in recent years though it remains a possibility if river discharge were to exceed bankfull.

From the above observations, a total adjustment of -7 was made, calculated as follows:

Code	Description or value	Rating
A2.a	Moisture pocket	1
C1.b	Moderate areas of damp rock	2
D2	Surcharge due to trees	1
H3.c	Local effect of large trees on	2
J2.b	face	-2
K2.a	Uniform, planar slope	-2
L1.a	Lack of fracture intersection	-9
	>80 years since excavated	
Total adjustment		**-7**

Table 2 *Total RDA Rating adjustment for Bongate Scar*

The adjusted RDA_A Rating, therefore, is 41 + -7 = **34**, which is a class 2, low risk slope, requiring a passive approach to mitigation.

1.2.2 Stage Two RDA

The slope fits neatly into the weak massive type. The relevant data sheet indicates a typical RDA_A Class of 2/3+, and associated deterioration modes of grain ravelling and grainfall as major modes, with wash erosion and scaling as minor modes. Stonefall can also occur. Since deterioration morphology is available, analysis of the relevant data sheets will help to confirm which of these deterioration modes is actually present. In practice, field observation showed a small number of sand piles at the foot of the slope, containing occasional flakes or spalls of intact sandstone. This indicates grain ravelling and scaling. There was also a general scatter of sand grains at the foot of the slope indicating grainfall, and a handful of stone-sized fragments indicating stonefall. As mentioned earlier, the slope provided evidence of waterflow over the surface and there was small scale fragmentation around large tree roots. These indicate a possible contribution of wash erosion and the potential activity of localised fragmentation due to root wedging.

1.2.3 Stage Three RDA

Reference to the deterioration mode data sheets should enable an assessment to be made of the most appropriate mitigation measures for this slope. The mitigation recommendations are based on the presumption that the consequences of deterioration would be unacceptable if not treated. On this basis, the recommended treatment for this slope would be crest and toe surface drainage and very infrequent removal of loose blocks or spalls. In reality, this slope is situated on private land but has been designated a Regionally Important Geological and Geomorphological Site (RIGS). A booklet produced by Cumbria RIGS Group (1994) on the geology of the Eden Valley ensures that this locality is visited frequently by educational groups and individuals. Nevertheless, the deterioration modes involved are unlikely to have any serious consequences. The exception to this is that there is the remote possibility, given the overhanging trees at the crest, for a significant collapse to occur, and thus occasional ongoing monitoring of this situation would be recommended.

1.3 Knock Pike Quarry: Irregular blocky rockslope

Knock Pike is a disused, bulk blasted quarry situated near Appleby in Cumbria at grid reference NY 687286. The rock is an ash flow unit with eutaxitic texture, formed from intense compaction of pumice fragments contained within. It is a fine crystalline, well cemented, slightly weathered, very strong IGNIMBRITE. The sequence is of Ordovician age, of the Knock Pike Tuff formation (Borrowdale Volcanic Group). The rock mass is dominated by random, blast-induced fractures and irregular joints, giving an irregular blocky structure overall (Plate 3).

Plate 3 Blast induced fractures at Knock Pike Quarry

1.3.1 Stage One RDA

The unadjusted RDA_U Rating for the slope is 49 and was calculated as follows:

Key parameter	Value	Rating
Fracture spacing	15cm	26
Fracture aperture	7mm	12
Rock strength	150MPa	4
Material weathering grade	Slightly weathered, locally moderately weathered	7
Unadjusted RDA Rating (RDA_U)		**49**

Table 3 *Calculation of RDA_U for Knock Pike Quarry*

On this basis, this slope is classed as being moderate risk (class 3). Adjustment factors were based on the following information:

Environmental conditions: The slope is located at an altitude of 335m. It has a north westerly aspect and is situated in high, open moorland. However, a vegetated hill opposite the quarry considerably reduces the amount of exposure. There is no direct or indirect evidence of groundwater seepage or regular surface runoff.

Stress conditions: The quarry does not appear to be subject to any dynamic stresses.

Engineering factors: There is no evidence of engineering intervention. The slope was excavated by bulk blasting, producing a set of irregular, closely spaced and wide aperture fractures.

Excavated slope characteristics: There is an extremely small amount of vegetation on the slope, mainly consisting of a few grasses and herbaceous plants, and there is no deterioration specifically associated with these. The slope is up to 30m high but more typically 25m and has a gradient of 54^{o} from the horizontal. The slope has been cut in a single lift but it has an irregular surface. Three of the adjustments pertaining to rock mass structure apply: K1.c applies because the total rating for mass properties (38) is greater than 35, and the total rating for material properties (11) is less than 30% of the unfavourable parameters. K2.b also applies because the blocks produced by irregular fracturing are highly interlocking (Plate 3). A negative adjustment must be made for K3 because although 15cm has been used in the RDA_U to define block size, the slope also includes much larger blocks of 30-50cm in places, though not sufficiently distinct in spatial distribution to zone the slope and apply a separate RDA.

Other adjustments: The age of the quarry is unknown, but judging from the presence and appearance of machinery lying around on the quarry floor, the size of quarry floor vegetation and the state of the access track, it has probably been quarried in the last 20 to 30 years. The quarry is not subject to any direct disturbance. From the above observations, a total adjustment of +5 was made, calculated as follows:

Code	Description or value	Rating
B1.a/	North westerly aspect	2
d	Slope height	5
J1.a	Much more favourable material	5
K1.c	properties than mass properties	
	Interlocking structure	-2
K2.b	Variability	-5
K3		
Total adjustment		**+5**

Table 4 *Total RDA Rating adjustment for Knock Pike Quarry*

The adjusted RDA_A Rating, therefore, is 49 + 5 = **54**, which is a class 3, moderate risk slope, requiring a semi-active approach to mitigation.

1.3.2 Stage Two RDA

The slope fits neatly into the irregular blocky type. The relevant data sheet indicates a typical RDA_A Class for igneous rocks of 2/3, and associated deterioration mode stone ravelling as the major mode, with stonefall and rockfall as minor modes. Grain ravelling, flaking, wash erosion, blockfall and rarely, debris flow, might also occur. Since deterioration morphology is available, analysis of the relevant data sheets will help to confirm which of these deterioration modes is actually present. In practice, field observation showed several large overhangs, highly fragmented beneath, and

probably the source of large, associated rockpiles from rockfalls (overhang collapse). Irregular structure chutes are also present, feeding large debris piles at the foot, indicating debris flow (Plate 4). There are poorly developed levee structures and lobe-like deposits associated with these. The slope also has a number of large, perched blocks indicating potential for stonefall and blockfall, varying length ledges acting as structural chutes, and evidence of block wedging in wide aperture fractures. In some areas, blocks are tightly interlocking, so although closely fractured, they appear stable. Observations of erosional and depositional landforms suggest that while generally stable, the rock mass structure is such that when deterioration by fall is triggered in an area, this releases a large volume of material to collapse also. Thus the principal deterioration modes are stonefall, rockfall and debris flow. There might also be some stone ravelling but evidence is hidden in the irregularity of the slope and the large amount of debris from the large magnitude events.

Plate 4 Knock Pike Quarry
Structure chutes with debris piles at the foot

1.3.3 Stage Three RDA

Reference to the deterioration mode data sheets should enable assessment to be made of the most appropriate mitigation measures for this slope. The recommended treatment for this slope would be scaling of perched blocks; protective measures (large rockfall ditch and reinforced or anchored fencing or barrier); regular debris clearance, inspection and monitoring; cut-off drain at the crest; underpinning of overhangs; local dentition or buttressing; and dowel reinforcement of key blocks. Local application of wire netting might also be helpful in areas where only stone ravelling is occurring (i.e. none of the large magnitude events are in evidence).

The deterioration modes involved here have the potential for serious consequences because of their high magnitude. However, the shallow gradient of the slope ensures that most release of material from the face is dominated by sliding and bouncing modes of transport rather than freefall. In reality also, this slope is situated on private land, though a public footpath passes close to the entrance of the quarry. Since access to the face is extremely difficult, it is unlikely that there is any serious hazard

for passers by and so the quarry could be left in its present condition without any mitigation. For minimisation of the potential hazard, a warning sign or access restriction (e.g. a boundary fence) would be useful.

1.4 M6 Dillicar: Fissile and layered/blocky rockslope

The cutting at Dillicar on the M6 in Cumbria is situated at grid reference NY 610002. The rock is a fine to medium grained, moderately (fissile areas) to strongly (layered areas) cemented, fresh to slightly weathered, strong to very strong METASEDIMENT, consisting of a slightly metamorphosed turbidite sequence with interbedded siltstone and fine sandstone. The sequence is of Upper Silurian age, of the Coniston Grits formation. The structure consists of inter-layered competent sandstones and siltstones, with fissile shaley layers (Plate 5). The overall rock mass could therefore be described as composite (layered), but the two zones (fissile and layered) have been evaluated separately.

Plate 5 M6 Dillicar
Interbedded competent sandstone and fissile shaley layers

1.4.1 Stage One RDA

The unadjusted RDA_U Rating for the layered slope is 28, and for the fissile slope is 50. Calculations are as follows:

LAYERED/BLOCKY SLOPE		
Key parameter	**Value**	**Rating**
Fracture spacing	35cm	20
Fracture aperture	0.4mm	2
Rock strength	140	4
Material weathering grade	Fresh to very slightly weathered	2
Unadjusted RDA Rating (RDA_U)		**28**

FISSILE SLOPE		
Fracture spacing	10cm	28
Fracture aperture	1.5mm	5
Rock strength	50	13
Material weathering grade	Fresh to very slightly weathered	4
Unadjusted RDA Rating (RDA_U)		**50**

Table 5 *Calculation of RDA_U for M6 Dillicar*

On this basis, the layered/blocky slope is classed as being low risk (class 2) and the fissile slope is classed as being moderate risk (class 3). Adjustment factors were calculated on the basis of the information given below, which pertains to both layered and fissile slopes unless otherwise stated:

Environmental conditions: The cutting is located at an altitude of 200m. It has a north easterly aspect and is extremely exposed, overlooking the Lune Gorge with open moorland across the valley to the east. There are many areas of light seepage flow and areas of general wet rock surface.

Stress conditions: The slope is not subject to any dynamic stress from quarry blasting, and although situated alongside a motorway, is also not subject to traffic vibration. This is because in addition to a grass verge at the foot of the slope which is commonly more than 15m wide, there is also a hard shoulder between the slope and passing traffic. Added to this is the fact that the motorway has a planar, well maintained surface and is situated on a fairly gentle gradient.

Engineering factors: The slope was pre-split blasted and a range of protective and reinforcement measures installed including wire mesh netting, rockbolts and crest and slope drainage. There is evidence that rock material weathering has occurred, probably due to moisture retention, in the relatively protected environment behind many boltheads.

Excavated slope characteristics: On the layered slope there is a significant cover of grass and sporadic shrubs. There are no shrubs in the fissile areas, and less grass cover. The slope has been cut to a height of 11m at a gradient of 64^o from the horizontal. Layered parts of the slope have few intersecting fractures and therefore adjustment K2.a must be applied. However, layered parts of the slope are also highly variable, containing very blocky and some intensely fractured zones, as well as small areas of fissile rock within it. A positive adjustment for variability therefore also needs to be incorporated.

Other adjustments: The slope was excavated in 1971 and therefore, at the time of writing had been excavated for 29 years. Excavation was by pre-split blasting, though this has not been completely successful. The slope is extremely unlikely to be disturbed, except for infrequent maintenance operations.

On the basis of the above observations, a total adjustment of +14 was made for layered/blocky slopes, and +9 for fissile slopes calculated as shown in Table 6. The adjusted RDA_A Rating for layered/blocky slopes, therefore, is 28 + 14 = **42**, which is a class 2/3, low to moderate risk slope, requiring a passive to semi-active

approach to mitigation. The adjusted RDA_A Rating for fissile slopes is 50 + 9 = **59**, which is a class 3/4, moderate to high risk slope, requiring a semi-active to active intervention approach to mitigation.

LAYERED/BLOCKY SLOPE			***FISSILE SLOPE***		
Code	**Description or value**	**Rating**	**Code**	**Description or value**	**Rating**
A1.c	High exposure and moderate altitude	3	A1.c	High exposure and moderate altitude	3
B1.a/b	North easterly aspect	2	B1.a/b	North easterly aspect	2
C1.c	Groundwater seepage and surface runoff	2	C1.c	Groundwater seepage and surface runoff	2
G1	Deterioration associated with stabilisation works	3	G1	Deterioration associated with stabilisation works	3
H3.a	Grass cover	-3	H3.a	Grass cover	2
K2.a	Regular, non-intersecting structure	7	L1.d	Time since excavation and pre-split blasting method	-3
K3	Highly variable rock mass	-3			
L1.d	Time since excavation and pre-split blasting method				
Total adjustment		**+14**	**Total adjustment**		**+9**

Table 6 *Total RDA Rating adjustment for M6 Dillicar*

1.4.2 Stage Two RDA

Layered/blocky slope: This part of the slope generally fits into the layered type but there are also regular blocky areas within it. The relevant data sheets indicate a typical RDA_A Class for metamorphic rocks of 1 to 3 (layered) and 2/3 (regular blocky). For layered slopes, major deterioration modes can be expected to be stonefall and stone ravelling, with minor modes of wash erosion and blockfall. Grain ravelling, flaking and rockfall might also occur. For regular blocky slopes, stone ravelling is also a major mode, with minor modes of stonefall, blockfall and rockfall. Minor modes include grain ravelling, flaking and wash erosion. Field observation showed that structural chutes were common, often with piles of stones at the foot indicating stone ravelling and small rockfalls (Plate 6). The latter were also indicated by several large rockpiles including blocks of 30 to 40cm. A general scatter of isolated stones and blocks at the foot indicated that stonefall and blockfall had also occurred (Plate 6). There was also evidence of draped grass on the slope indicating wash erosion.

Plate 6 General view of M6 Dillicar showing the range of debris at the slope foot

Fissile slope: This part of the slope neatly fits into the fissile (layered) type. The relevant data sheet indicates a typical RDA_A Class of 1 to 4 for metamorphic rocks, and associated major deterioration mode of flaking, with grain ravelling and wash erosion as minor modes. Stone ravelling, stonefall and rockfall might also occur. There was considerable evidence of waterflow and associated erosion over the surface, indicated by flattened and draped grass, accumulations of fines and soil on ledges, the presence of vegetation, especially a widespread cover of grass. There were also several soil overhangs near the top of the slope and associated debris at the foot indicating grain ravelling. There were steep piles of platey debris at the foot of near vertical fissile layers indicating flaking. These bands were commonly up to 30cm in width and were effectively acting as erosion chutes. In some localities where flaking was undermining more competent strata above, a range of stones and blocks were scattered at the foot, indicating limited stone ravelling, stonefall and blockfall.

1.4.3 Stage Three RDA

Assuming that the consequences of deterioration would be unacceptable if no action were taken, the recommended mitigation for this slope would be as follows: *Layered/blocky areas:* Regular debris clearance and removal of woody shrubs; crest drainage and inclined drainholes at critical slope locations; containment using rocktrap ditch and fencing; local wire mesh netting for areas of stonefall and ravelling, with dowel reinforcement of key blocks for areas prone to blockfall. *Fissile areas:* As for layered/blocky areas (since these two zones are part of the same slope), and toe and slope drainage; very close mesh wire or plastic netting for areas with flaking; shotcrete or local mortar screeding for small, weak areas; dentition for small overhangs; and shotcrete sealing of fracture and erosion chutes.