INTRODUCTION TO RDA (ROCKSLOPE DETERIORATION ASSESSMENT)

Introduction

Observations in disused limestone quarries in Derbyshire, UK prompted questions on the applicability of existing weathering and rock mass classifications, and forms of numerical analysis for assessing the small but frequent falls of rock which were evident. Evaluation of discontinuity-controlled and deep-seated slope failures is standard practice at the design stage for rock excavations. However, there is no systematic approach to the assessment of shallow surface processes and progressive, weathering-induced erosion. This is because deterioration is often not perceived as a significant risk, it is difficult to quantify and its mechanisms are poorly understood.

Deterioration is defined here as shallow, progressive, physical and chemical alteration of rock material *and* its subsequent detachment and removal or re-distribution by transport agents. It is usually small in scale relative to more deep-seated failures but it is difficult to specify precisely the size of event involved. The term *deterioration* is useful because it encompasses the combined results of weathering, detachment and transport acting on a rockslope, manifest as a range of erosive processes and small scale mass movements. The term has not commonly been used in engineering geology, nevertheless, there are several examples of its use in the context of small scale rock breakdown mechanisms (e.g. Kirkwood & Dolecki 1993; Topal & Doyuran 1997; Wüst & McLane 2000). Deterioration occurs because excavation disturbs the rock mass by releasing confinement, leading to expansive recovery (Gerber & Scheidegger 1969; Feld 1966; Nichols 1980), and because excavation exposes a rock mass to ambient environmental conditions such as fluctuations in temperature and moisture. Equilibrium is re-established through progressive and accelerated breakdown and erosion of the slope (Gunn & Gagen 1987).

An investigation was conducted in which 210 slopes around the UK were observed and evaluated. Interviews with highway authorities and quarry operators were also undertaken with a view to obtaining anecdotal evidence of deterioration hazards. The assessed slopes comprised 46% road cuttings and 46% disused quarry faces. A small number (6%) were situated in active and semi-active quarries and 2% were natural rockslopes. Approximately half the slopes investigated were cut in sedimentary rock, while igneous and metamorphic rocks made up equal proportions of the remainder. Most of the commonly occurring rock types in the UK are represented in the investigation (see Nicholson 2000). The field investigation revealed that although deterioration is widespread, both geographically and lithologically, the nature of the hazard varies enormously and the potential consequences of deterioration are strictly dependent on site-specific factors. The safety hazard posed by small scale, weathering-related breakdown of slopes has been recognised by others (e.g. Bunce *et al.* 1997; Walton 1988). However, anecdotal evidence obtained during the course of this investigation also revealed deterioration to be a significant engineering problem. This is because deterioration has the capacity to weaken the rock mass and material, reduce support and modify slope morphology in a way which is difficult to predict, both temporally and spatially. Furthermore, these modifications may affect the slope throughout its design life and may result in a significant resource burden through unplanned requirements for maintenance and remediation. Additionally, anecdotal evidence was obtained that resource wastage occurs due to over-design, or excessive and unnecessary inspection and monitoring. Full findings of this field investigation are presented by Nicholson (2000) and selected results and case studies are presented by Nicholson & Hencher (1997) and Nicholson (2003).

Current approaches to slope hazard assessment

Many of the current approaches to assessment and classification of rock masses (e.g. Geological Society Engineering Group Working Party 1977; Bieniawski 1989) and their stability (e.g. Hack 1998, Hack *et al.* 2003) contain elements which could be used in the evaluation of rockslope deterioration. However, these methods were not specifically designed for that purpose and therefore have a number of inadequacies and limitations in this respect. For example, the Rock Mass Rating system devised by Bieniawski (1973, 1976) and modified by Romana (1988) for use in slope stability assessment, was designed for modes of failure which depend upon the presence of distinct discontinuity planes. This is also true for kinematic analysis using stereographic projection techniques (e.g. Hoek & Bray 1981; Walton 1988) and for limit equilibrium analysis (e.g. Nash 1987). In theory, the movement of even a small fragment of rock within a slope will usually involve some element of sliding or toppling and could therefore be analysed using these concepts. However, analysis of the stability of individual rock fragments constituting a large rockfall, for example, is simply not practicable. In practice, many forms of weathering-related deterioration are independent of large scale discontinuity planes.

Most rock mass classifications have been designed to evaluate support requirements for tunnelling and other underground excavations in rock (e.g. Barton *et al.* 1974; Laubscher 1977; Bieniawski 1973; Kendorski *et al.* 1983). Selby (1980) and Romana (1988, 1993) have developed rock mass classifications specifically designed to address slope instability, the former for natural slopes and the latter for excavated slopes. However, even where specifically designed or modified to address slope stability (e.g. Hack *et al.* 2003), rock mass classifications are not generally applicable to deterioration problems. This is illustrated very clearly by Ross & Reeves (1995) who applied several analytical methods to two igneous highway slopes in Scotland. They found that rock mass classification, stereographic projection and discontinuity analysis failed to match the actual maintenance requirements of the slopes under consideration.

A number of weathering classifications have been published (e.g. Moye 1955; Ruxton & Berry 1957; Chandler 1972; Geotechnical Control Office 1988; Martin & Hencher 1986; Geological Society Engineering Group Working Party 1995), but these are designed to provide a description of the static condition of the rock mass or material as a result of past weathering and do not attempt to address time-dependent processes or the susceptibility to future weathering. They also do not consider the dynamic transport phase of deterioration which is critical in determining its effects and thus its mitigation.

Several slope and rockfall hazard assessment schemes have been published (e.g. Sinclair 1992; Bunce *et al.* 1997; Franklin & Senior 1997a, 1997b; McMillan &

Matheson 1997, 1998) and a number of rockfall trajectory studies have been conducted (e.g. Ritchie 1963; Mak & Blomfield 1986; Spang 1987; Robotham *et al.* 1995). Again, there are elements of these which would be useful in the evaluation of rockslope deterioration, but many were designed for purposes which restrict their applicability in this context. Some schemes, for example, emphasise slope failure by rockfall but do not deal with the wider range of slope processes relating to weathering. Others address natural, rather than excavated slopes, or are applicable to specific conditions in a very limited geographic area. Some schemes also emphasise the mechanism of fall but not its likelihood, consequences or mitigation. Very few rockfall hazard assessment methods are applicable prior to excavation (i.e. *proposed* slopes). The Rockfall Hazard Rating System (RHRS) (Pierson *et al.* 1990) and its subsequent modification by others (e.g. Franklin & Senior 1997a; Budetta 2003) contains several rating components (e.g. average vehicle risk, roadway width and rockfall visibility) which restrict its use to slopes alongside roadways.

Rockslope Deterioration Assessment (RDA)

As a result of the field investigation referred to above, a new, three-stage approach to slope hazard assessment, called Rockslope Deterioration Assessment (RDA), is proposed (Figure 1). Throughout, the terms *hazard* and *risk* follow definitions by the International Union of Geological Sciences (IUGS) Working Group on Landslides, Committee on Risk Assessment (1997). Usage of the term *susceptibility* follows Harp & Noble (1993) where the term describes the *relative potential* for a rock mass to deteriorate. Susceptibility can be regarded as a component of the deterioration hazard (Chowdhury & Flentje 2002).

RDA addresses shallow, weathering-related erosional processes and mass movements. In RDA stage one the susceptibility of a rockslope to deterioration is assessed semi-quantitatively by the application of ratings to a range of selected intrinsic and extrinsic factors. In stage two, the nature of the deterioration hazard is assessed qualitatively with reference to rock mass type and slope morphology. In stage three, guidance on appropriate mitigation is provided, based on the findings of stages one and two.

A deductive, *a priori* approach was used to develop the RDA method: Deterioration nature and potential for a given slope was predicted in advance of field observation on the basis of current, established knowledge of weathering processes and the role of intrinsic properties and external influences. This prediction was used to determine appropriate RDA ratings and adjustment factors which were then modified and refined in the light of field investigation as part of an ongoing, iterative process.

The primary aims of RDA are to:

- provide a relative measure of the *susceptibility* or potential for rockslope deterioration based on an evaluation of selected criteria;
- enable the *nature* of the deterioration hazard to be determined and evaluated;
- indicate appropriate slope treatment and maintenance measures.

There is no attempt in RDA to *accurately* predict the magnitude, frequency or timing of the deterioration hazard. Current knowledge of weathering and slope processes is probably inadequate to achieve this anyway. However, certain inferences about magnitude and frequency can be made if the type of deterioration hazard has been identified. RDA is applicable to existing and proposed excavated slopes in rock, such as road cuttings and disused quarry faces. With caution, RDA can be applied to natural, as well as man-made slopes. RDA concerns slopes where the primary agent of slope modification is in situ weathering and subsequent transport of the weathered product. Therefore, it is not appropriate in situations where the primary agent of slope modification is an erosive process such as natural marine or fluvial undercutting, or active, ongoing excavation by Man. The numerical probability and potential losses (i.e. risk) associated with deterioration hazards are not specifically addressed in RDA. The risks associated with deterioration are inevitably a function of a number of factors including adjacent land use, vehicular and pedestrian access, the nature and vulnerability of potential casualties (e.g. human, animal, structural, vehicular) and proximity of potential casualties. These factors need to be addressed on a site by site basis. Unlike other rockfall hazard assessment methods, RDA is not intended to be an inventory system with the objective of assigning priority for treatment. It is intended for evaluation of deterioration hazard for the specific slope under investigation. That said, RDA stage one does enable slopes to be compared against each other on the basis of their intrinsic mass and material properties.

There are a number of benefits in the application of RDA:

1. Properties or conditions most critical to rockslope deterioration susceptibility are identified, resulting in a form of qualitative sensitivity analysis.

2. Rockslopes can be sub-divided into zones of similar deterioration susceptibility and those zones requiring more detailed investigation or monitoring are highlighted.

3. An RDA class is assigned for a given range of characteristics and represents the degree of hazard susceptibility. This class forms the basis of guidance on the nature of the hazard and its mitigation.

4. Application of RDA enables comparison of different rockslopes and thus provides a common basis for communication.

5. Field investigation necessary for RDA provides quantitative data which can be used in slope design, deterioration mitigation and maintenance planning.

6. The method is widely applicable, requires little data input and enables rapid assessment.

Many of the above follow Bieniawski's (1989) reasons for classifying rock masses in general.

Prior to application of RDA a preliminary appraisal should be undertaken to sub-divide the rockslope into relatively homogenous zones (or structural regions and domains, Piteau 1973). Each zone should be assessed separately and a unique RDA

Rating established for each. Where zones are not sufficiently distinct to be treated separately, engineering judgement must be applied to determine an appropriate assignment of ratings. Several options are possible:

- RDA can be applied to the groups of properties which are most common (ie those covering a larger proportion of the slope).
- RDA can be based on properties which appear to be contributing more to deterioration (this requires experience and judgement).
- RDA can be based on mean values can be adopted (though this can render the assessment relatively meaningless).
- RDA can be based on the worst case scenario (ie conduct several RDA's and select the worst).

In any event, the relevant adjustments for rock mass variability should be applied as necessary (see stage one document).

If the rockslope being assessed already has successful stabilisation measures in place, ratings for key parameters should reflect this. For example, if multiple blocks are effectively behaving as a single block because of rockbolt reinforcement, discontinuity spacing should be reduced accordingly, or if fractures have been grout-sealed, discontinuity aperture should be regarded as zero. Where the surface of the rock has been covered, by shotcrete, for example, the rock should be classified as unweathered (fresh) and intact (with no discontinuities). Where mitigation measures merely reduce the consequences of deterioration (eg netting, rocktrap ditch), values for key parameters should be determined in the normal way.

Over a period of three years, MSc engineering geology students have assisted in testing RDA by applying to slopes in West Yorkshire and Cumbria during fieldwork. Despite receiving no prior training in the use of the method, over 70% of ratings assessments made by students (RDA stage one) were within half an RDA Class of ratings determined by the author. This indicates a high level of reproducibility and a minimal training requirement. Some modifications to earlier versions of RDA were made in response to its evaluation by these students to facilitate use. RDA can be undertaken rapidly, largely through visual inspection and with minimum use of field equipment. Experience suggests that the time required to undertake a full RDA depends on the level of pre-existing knowledge of the slope and location, the amount of variability inherent in the slope and the experience of the operator. A complex slope which required sub-dividing into several zones might take two to three hours to assess fully, but a simple, single unit slope could be assessed in 30-60 minutes. If a pre-excavation RDA has already been undertaken on the basis of desk study information, a refined RDA could probably be completed in around 30 minutes. RDA places only minimal requirements for equipment (e.g. geological hammer, tape, caliper or ruler, compass clinometer).

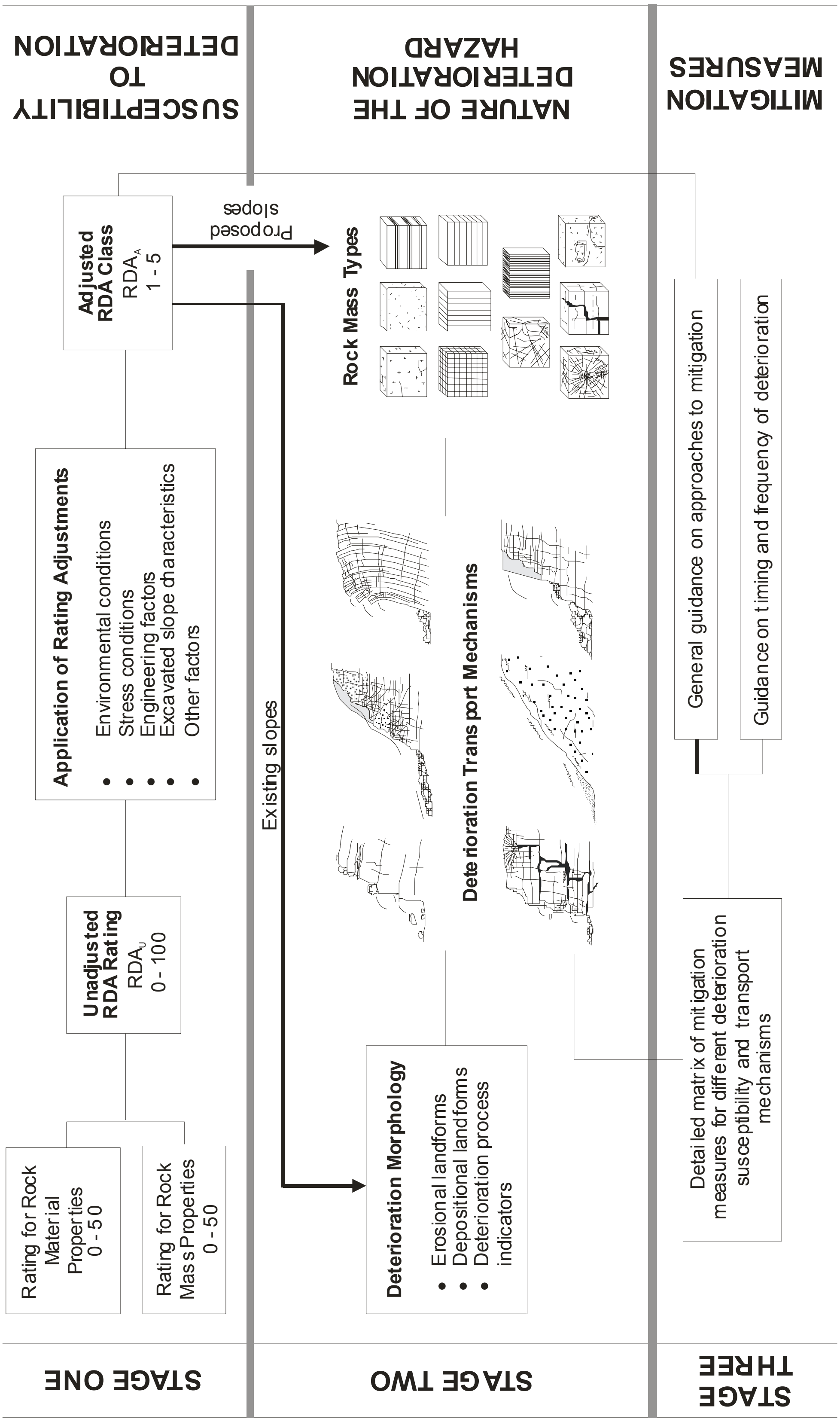

Figure 1: Structure of RDA (Rockslope Deterioration Assessment)

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