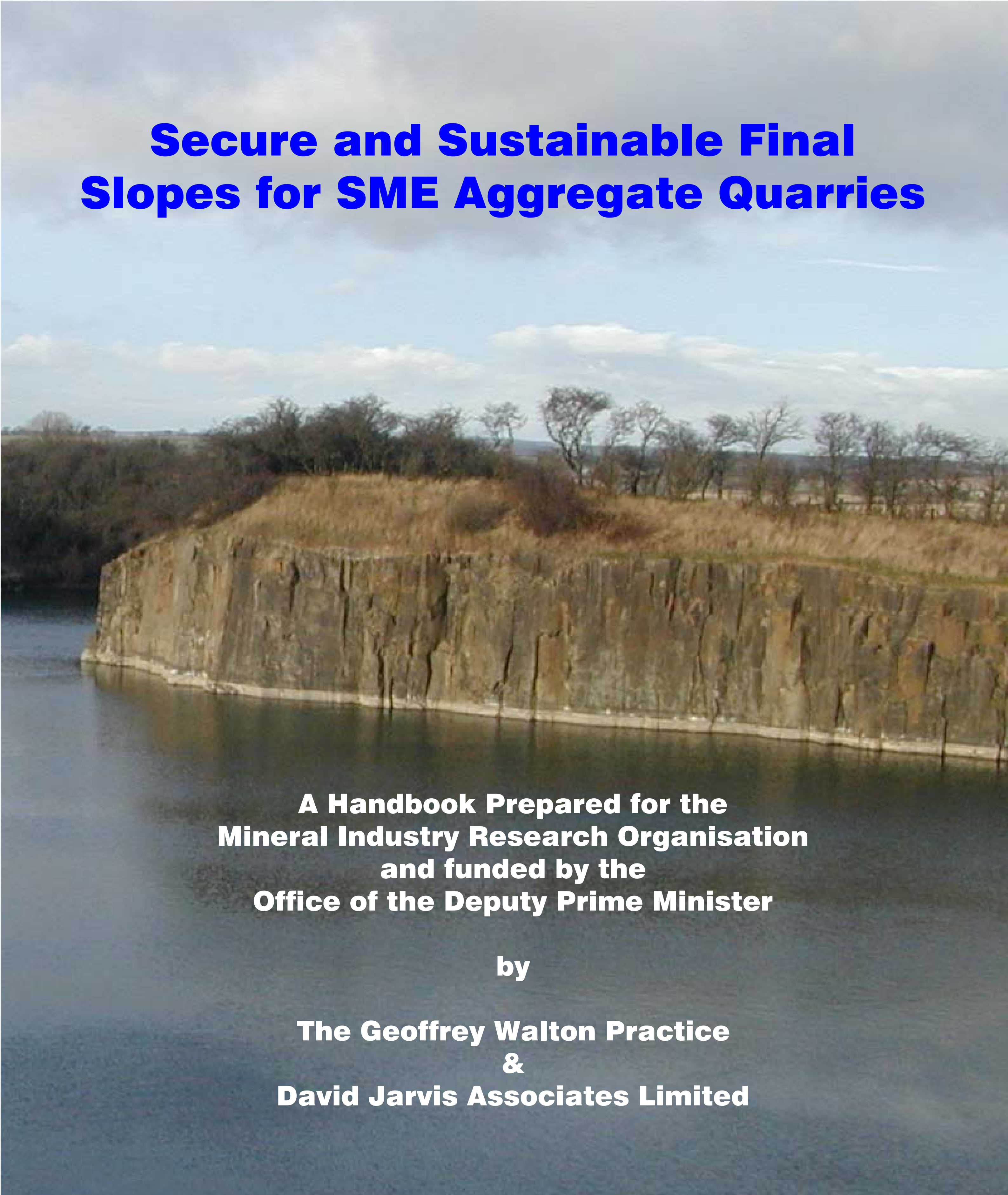

Secure and Sustainable Final Slopes for SME Aggregate Quarries

A Handbook Prepared for the Mineral Industry Research Organisation and funded by the Office of the Deputy Prime Minister

by

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First published March 2004

Published by
Jon Carpenter, Evenlode Books
Market Street, Charlbury, Oxford
OX7 3PH

ISBN 0897766882

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This handbook deals with the need for, and methods of obtaining, secure and sustainable final slopes in SME quarries. These small and medium sized firms rarely have in-house geotechnical or landscape personnel and often need to know where to go for information and technical advice. The issues and interested parties are noted and the findings are based on many visits to quarries. These include stability and the HSE, Mineral Planning Authorities, English Nature (with Geological Sites of Special Scientific Interest) and local interest groups (concerned with Regionally Important Geological Sites). The different types of quarries and their settings are then outlined; these include hilltop, valley bottom, hillside and coastal quarries in all the main aggregate types worked in SME operations. General approaches to slope treatment are then discussed including landform replication, restoration blasting, ground preparation and excavation, the use of quarry waste materials and vegetation and planting within the context of the design, construction and management of final slopes.

A simplified outline of stability and safety is then provided having regard to the range of after-uses at the end of quarrying. Final slopes need to be consistent with intended after-uses. The factors affecting different types of slope failure are noted and different modes of failure are described. Approaches to the design of slopes are then briefly mentioned with regard to the legal requirements for slope design and the assessment of geotechnical risk in those slopes that represent significant hazards. Rockfall is seen as the principal concern at most final slopes and methods of its assessment, control and management are outlined.

A more specific review is given of different ways to plan, design, construct and manage the various elements of final quarry slopes. Advice is given regarding slope crests, bench faces, benches and the toes of overall slopes. Examples are shown in photographs of good and unsatisfactory practice with respect to the slope elements.

The concluding sections of the handbook cover the general findings of the landscape aspects of these quarries. A number of generic mistakes and missed opportunities are noted and also some of the high spots in terms of current SME practice. The geotechnical conclusions cover the use and sizing of benches, the significance and avoidance of rockfall and the widespread need for improved face scaling. There is also a need to re-appraise access arrangements to geological SSSIs in quarries having regard to increasing levels of safety awareness. In general it is considered that the Quarries Regulations are beneficially impacting on the safety and configuration of final quarry slopes.

Appendices include references and further reading, *proformas* that SMEs can use to appraise hazards within their final slopes and the visual impacts of these faces in the local landscape setting. A sequential checklist of steps to be followed in designing, constructing and managing final slopes is also provided together with a glossary of terms.

Synopsis

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Background and project objectives

This handbook has been prepared by the Geoffrey Walton Practice and David Jarvis Associates Limited as part of a study into the need for and the methods of obtaining secure and sustainable slopes in the smaller quarry operations in England.

Small and medium-sized aggregate companies (SMEs) rarely have in-house geotechnical and landscape support to advise on, and to undertake slope design and related landscaping. The final slopes of a quarry need to comply with the 1999 Quarries Regulations [41] and to be left in a safe condition (Reg.6 (4) and guidance with Reg.45). They may also require specific specialist design in a number of frequently occurring situations (Reg.32 and Reg.33). Quite apart from the impositions of the regulations and related costs on SMEs, there is often the need to ensure that final restoration of ultimate slopes is visually acceptable.

In the past the maximisation of mineral recovery by the operator was seen as an over-riding concern. This has sometimes led to over-steep slopes formed too close to site boundaries for visual enhancement or even subsequent slope stabilisation or maintenance and may also preclude beneficial and even lucrative after-use alternatives. Secure and sustainable slopes are also of relevance with respect to geological conservation sites. These sites, typically geological SSSIs (designated sites of special scientific interest) or RIGS (regionally important geological sites) are especially vulnerable to long term erosion and local collapse or rockfall. Such hazards may prevent safe access and defeat the objectives behind their establishment. In extreme cases degradation of slopes can give rise to significant hazards outside the site boundary.

Potentially and taken together, the Quarries Regulations, restoration requirements and the Aggregates Levy represent an increasing cost burden for small firms. This handbook aims to give the mineral operator and regulatory authorities a basic grounding in the relevant issues and regulations with respect to long term security, landscaping and the planning for what works are required. This is becoming evermore relevant as SMEs can sometimes receive contradictory advice from different specialists. For example, geotechnical specialists who design secure slopes seldom have a detailed understanding of landscape planning objectives; similarly in some cases landscape designs may be lacking in attention to slope stability and especially with respect to long-term erosion or security.

The development of this handbook has been funded under the Sustainable Land-Won and Marine Dredged Aggregate Minerals Programme, established by The Office of the Deputy Prime Minister. The programme provides funding for aggregate minerals research that is consistent with the objectives of the Aggregate Levy Sustainability Fund. This aims to improve the information base on aggregates and environmental constraints and to support the improvement of environmental management practices so that impacts can be reduced. Hence this handbook seeks to provide information and examples of good practices thereby encouraging better liaison between mineral operators and neighbouring communities.

Why sustainable slopes?

Sustainability in environmental terms is defined as the amount or extent to which the Earth's resources may be exploited without damage to the surroundings. A sustainable slope is by extension a long-term structure that does not cause serious environmental damage. The government's Mineral Planning Guidance Note 1 (1996) deals with sustainable developments and indicates that any development, including for example the formation of a long term final quarry slope, needs to consider the costs and benefits involved especially environmental costs and benefits [20]. In minerals planning the objectives for sustainability are:

- Conservation of minerals whilst ensuring adequate supply.
- Minimisation of environmental impacts.
- Efficient use of waste materials.
- Sensitive working, restoration and after-care to enhance overall environmental quality.
- Protection of designated landscape and conservation areas.
- Avoidance of sterilisation of minerals.

Clearly final slopes should be designed and constructed to protect designated landscape areas and conservation sites. The use of quarry waste materials in restoration and the maintenance of secure long-term slopes beyond the restoration and after-care periods are quite consistent with this objective.

Quarries Regulations

Part of the background to this project has been the relatively recent introduction of the Quarries Regulations and a mandatory Approved Code of Practice (ACoP) in 1999. This has brought in a significant number of changes compared with the previous Acts and Regulations that dated from the 1950s. Of particular relevance was the introduction of clearly defined requirements in respect of the design and construction of quarry slopes (Regulation 30). That imposes a duty to ensure the safety of excavations. It also requires detailed investigations to support the design of excavations if overall rock slopes were more than 30m high, or bench faces more than 15m high, or if benched overall slopes between 15 and 30m were steeper than 45 degrees (Regulations 32 and 33 and ACoP). There are cost implications for the operators of SME quarries, but the consequences of neglecting to attend to stability issues can be serious and could result in enforcement actions from the HSE including improvement or prohibition notices or prosecution with the risk of heavy fines and imprisonment.

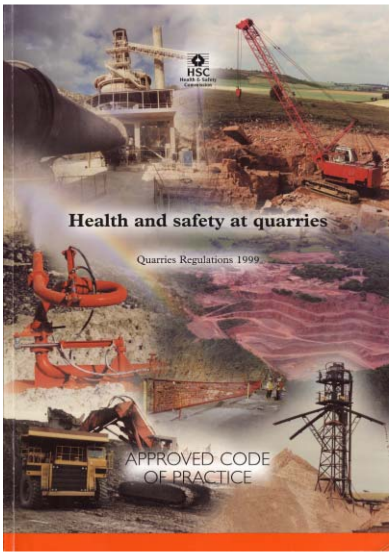


Fig. 1.1 Quarries Regulations 1999

The 1999 Regulations also require that … "*the operator shall ensure that in the event of the abandonment of or ceasing operations at a quarry, the quarry is left, so far as is reasonably practicable, in a safe condition*" (Regulation 6(4)). The guidance to the Regulations indicates that the quarry operator must consider the geotechnical features of the site and the proximity to the site of houses, roads, footpaths and the health and safety of employees and the public both during and after quarrying. It should also be noted that any accumulation of any substance in a quarry is now regarded as a tip including materials used in restoration (Regulation 2). Many of the final slopes discussed and illustrated in this report incorporate such tips; owners of disused tips remain responsible for the safety of these tipped restoration materials following the abandonment or closure of a quarry.

Government Policy

Although general guidance on policy relating to matters such as final slopes is given in Mineral Planning Guidance Note 1 (MPG1) more detail is given in MPG7 on the Reclamation of Mineral Workings [20] [21]. This states that restoration should "*maintain or, in some circumstances, even enhance the long-term quality of land and landscapes taken for mineral extraction.*" For a number of years mineral planning applications have been required to develop site-specific landscape strategies including:

- Defining key landscape opportunities and constraints.
- Consideration of the potential directions of working, waste material locations and extent of visual exposure *etc*.
- Identifying additional screening requirements.
- Identifying after-uses and preferences for the restored landscape character.

Of particular interest it notes that …"*wherever possible and safe to do so the natural gradients and rock features of the surroundings should be imitated when forming new screening banks and final faces.*" It recognises that the gradients of final slopes are a compromise between mineral resource recovery and acceptable landscape fit, and notes that a reclamation margin beyond the mineral recovery boundary can be suitable for reshaping production faces for reclamation purposes.

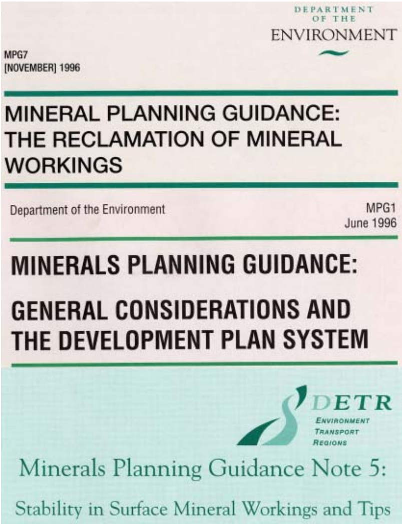


Fig. 1.2 Minerals Planning Guidance

Above all this, the MPG notes that reclamation must match the intended after-uses and draws specific attention to the hazard represented by rockfall in final quarry faces. The possible need for scaling, inspection and other stabilisation measures to secure final slopes is noted. Unfortunately at many sites in 2003 and 2004 little still appears to have been done to rectify matters noted in the MPG eight years ago.

Authors' experience

Over the last 25 years the authors' firms (GWP and DJA) have worked on more than 450 quarries providing advice on mineral reserves, quarry planning and design, geotechnical investigations of excavated slopes and tips, and landscape design, visual impact assessment of quarry developments and planning and after-use activities. One of the firms (GWP) has been much concerned with the practical implications of the Quarries Regulations 1999 since a partner (GW) served on the advisory panel during the drafting of the legislation.

In consequence the particular concerns of SMEs are appreciated since production levels and sales revenues often do not allow for very detailed investigations of the geology or the geotechnics of a quarry or substantial investment in restoration. In some cases the smaller firms with only one quarry have shown little interest in the appearance or end-use of the quarry since there may be little opportunity for owning or even leasing a comparable operation elsewhere. Basic interests may seldom extend beyond reaching and holding modest production levels and commonly the fundamental principles of quarrying and quarry design and layout are poorly understood. Generally there has been little or no design of slopes and the restoration and landscape arrangements are something for the future. There are of course exceptions in the activities of the SMEs and it has been rewarding to see a number of successful schemes at some of the sites visited. Company size is of course no safeguard in respect of the safety or appearance of final slopes. Unfortunately it is also possible to point to some less satisfactory current and former quarry operations by much larger organisations who at times appear to concentrate activities on some excellent examples while other sites with little prospect of extension, improvement or other development in the vicinity are very poorly restored often with unstable final slopes.

Quarry visits and other meetings and discussions

The interested organisations and parties visited, and the approach to the assessment of completed slopes in terms of both stability and visual impact *etc*., were based on experience of many similar appraisals and assessments elsewhere. SME operators comprised the bulk of the quarry visits although some sites operated or previously worked by larger firms were inspected. The authors wish to express unreserved gratitude to the many firms involved who permitted visits and who often went to considerable lengths to provide information, who visited specific faces of quarries with the authors and discussed their approach to final slopes in some detail. Hopefully this handbook in some way will reflect our gratitude to them for their time and effort. To protect confidentiality it will be appreciated that the location of individual quarries, the names of the quarrying companies and the staff to whom the authors spoke have not been disclosed. The authors apologise if inadvertently quarries or companies can be identified.

The proposal allowed for visits to 45 aggregate quarries in England. The intention was to spread the visits in a rational fashion through the country and to include the principal aggregate types: limestone, sandstone, igneous and metamorphic rocks and sand and gravel operations. Workings were visited in 16 Mineral Planning Authorities including 5 in Southwest England, 5 in the Midlands and Southeast England and 6 in Northern England. These included most of the major aggregate quarrying districts in England. An attempt was also made to balance the rock types to the number of working SME quarries and the national output of these quarries, although other considerations intervened since few sand and gravel operations had significant final slopes and some of the visits were to dormant or closed quarries rather than current workings with restored slopes.

The visits comprised prior assessments of the geology of the site, an overview of the landscape setting and the appraisal of the visual impact of the workings. The quarry visits concentrated on work at active final quarry faces and final faces in various stages of restoration. An attempt was made to ensure some deep as well as shallow final slopes were visited. 11 of the quarries visited had overall slopes of 45 to 60m and 4 exceed 60m in height. 7 quarries were less than 15m deep (mainly sand or gravel) but the majority had slopes of between 15 and 45m. In the bedded strata the majority were sub-horizontal (strata dips of less than 7 to 8°) but 15 were in inclined strata and 9 were in generally massive rock (igneous or metamorphic).

Since the range of geotechnical settings was somewhat limited a further 10 quarries were visited for only geotechnical reasons to ensure that an adequate number of slope configurations was appraised. These included 3 quarries in Eastern Wales to allow for an assessment of geotechnical issues related to landform replication (see Chapter 4).

Visits ranged from between 2 to 4 or more hours. On a number of occasions copies of the geotechnical appraisal of final slopes were subsequently sent to the quarry owner or operator. Both owners and operators were included amongst the people who attended the quarry visits.

Useful meetings were also held with English Nature and about 18% of the quarries visited included Geological Sites of Special Scientific Interest (SSSIs). Several meetings or lengthy discussions were held with MPAs who recommended a number of the sites visited including both good or excellent and unsatisfactory or poor examples.

Finally MIRO staff have been helpful and supportive with the conduct of this study. However the responsibility for the accuracy of the contents and the opinions expressed herein are the authors and not necessarily those of MIRO or the Office of the Deputy Prime Minister.

Contents

This handbook is primarily intended for SME aggregate quarry owners and for operators, but others in minerals planning and related environmental or conservation sectors may find it helpful. It assumes a basic understanding of quarry geology such as would be obtained from that part of the first year of the Doncaster Distance Learning Quarrying Course dealing with basic geological concepts. These include bedding, jointing, faulting and rock types and geological settings generally associated with the main aggregate rock types. The handbook seeks to cover the principal issues relating to final slopes and give guidance to those who frequently have built up their businesses through endeavour and self help. Often SMEs are understandably loath to take professional advice for reasons of cost; the authors have however noted where such advice might be appropriate and where it is likely to be mandatory to satisfy outside agencies such as the HSE or planning authorities.

Chapter 2 of the handbook considers in more detail issues and interest groups concerned with final quarry slopes. These include owners and operators of SME quarries, the HSE and its use of the Quarries Regulations, Mineral Planning Authorities and relevant planning guidance from central government and English Nature and other interest groups.

Chapter 3 covers the general settings and different types of quarries and the various rock types worked in England for aggregate.

Chapters 4, 5 and 6 include sections on the means whereby final slopes can be made safe and secure and the sometimes conflicting interests of stability and landscape can be addressed.

Conclusions are presented in Chapters 7 and 8 and appendices include references and further reading, survey proformas for geotechnical and landscape appraisal, a sequential checklist for final slopes and a glossary of terms.

Users may read this as they wish. For example they may prefer to dip into the handbook for specific items of interest; the appendices include proformas for the appraisal of geotechnical hazards relating to excavated rock slopes, slopes in weaker rock and soils including overburden and slopes in tipped materials. They also contain a simple checklist of steps to be followed when undertaking a basic design of a final slope in both landscape and geotechnical terms. Others may find the section on how to handle different elements of a final slope from the crest to benches and bench faces to the toe helpful when considering alternative slopes and slope treatments.

The authors would welcome criticism of this handbook (as well as encouragement). The text is available on *www.sustainable-slopes.org* and there is a notice board where comments can be made at this website. The authors will endeavour to update the electronic version of the handbook periodically to accommodate further information or changes in the technical or legal context in which quarries operate.

Introduction

This chapter comprises a brief review of the requirements of the Quarries Regulations 1999 regarding excavated slopes, their design, construction and operation. All working British quarries are required by law to comply with these Regulations and the accompanying Approved Code of Practice (ACoP). The Regulations were drafted in discussion with representatives of various quarrying and industry related groups. Compliance is monitored by the Health and Safety Executive who have powers to impose improvements, to stop unsafe operations and if necessary to prosecute those not complying in the event of accidents (fatal or otherwise) or dangerous occurrences. This chapter summarises relevant sections of the Regulations relating to slopes.

It then goes over attitudes to final slopes based on meetings and correspondence with other interested parties. These range from the operating companies and some mineral owners to Mineral Planning Authorities (MPAs) and the parallel planning authorities involved in conservation and other environmental matters. English Nature is also much involved where a quarry or part of a quarry is a geological Site of Special Scientific Interest (SSSI). Finally local interest groups and residents' associations sometimes have interests or concerns that include final slopes.

Stability and the HSE

Aspects of slopes are covered in Regulations 13, 16 and 30 to 37 of the Quarry Regulations 1999. Definitions and other relevant issues such as inspection requirements, health and safety documentation and blasting controls are also included elsewhere in the Regulations.

The guiding regulation is No. 30 which states that … "*the operator shall ensure that excavations and tips are designed, constructed, operated and maintained so as to ensure that (a) instability or (b) movement which is likely to give rise to risk to the health and safety of any person is avoided*". This includes any excavated face whether internal or final and whether in bedrock or superficial materials; it covers all excavations (and tips) however small. As noted previously, tips are now defined so as to include any accumulation of any material whether permanent or not and any liquid pond or lagoon.

The ACoP requires all slope design to be based on a site investigation that includes desk studies, survey results and any relevant, historical information about the site and its surroundings. Schedule 1 of the Regulations lists the components of the information to be collected. Obviously the more complicated the site in geological terms and the more critical the setting in respect of safety considerations, the greater the attention that has to be given to design. Several publications and text books exist that give guidance on the basic constraints to slope stability in quarries [44] [31] [32]. Detailed discussion is beyond the scope of this handbook although some basic guidance is given in Chapter 5. It should be appreciated that final slope design ought to conform to good engineering practice and relevant standards and that designs may need to change in the light of information obtained during routine working, inspection and appraisals.

The Quarries Regulations introduced a system to ensure that those excavations and tips that have the greatest potential for harm to those inside or outside a quarry are assessed in the greatest detail. Hence there are two steps to be followed when considering existing or proposed slopes:

i. Hazard appraisal.

ii. Geotechnical assessment of the significant hazards.

In the context of the Regulations hazards are defined as the potential to cause harm to the health and safety of any person. The hazard appraisal is meant to be a straightforward exercise that can be objectively completed by a competent, experienced employee of the operating company. Appendix 2 of this handbook sets out proformas with a scoring system that can be used to appraise the hazards from rock slopes and soil slopes as well as solid tips in quarries. The higher and steeper quarry faces are regarded as significant hazards and following the ACoP to Regulation 32 are listed below:

Rock slopes comprise significant hazards when:

- Bench faces exceed 15m in height or when,
- overall rock slopes exceeding 30m in

height measured from the toe to any point within 30m of the crest of the excavation or when,

- benched rock slopes between 15 and 30m in height that are steeper than 1 in 1 (45°) or when,
- other factors including visible slope distress, location or geological conditions indicate adverse conditions.

Soil slopes (as in sand and gravel operations or as overburden to rock slopes) comprise a significant hazard when:

- Bench faces exceed 7.5m in height and the face angle is steeper than 1 in 2 (27°) or when,
- overall soil slopes, as defined for rock slopes, exceed 30m or when,
- other factors indicate adverse conditions.

Solid tips comprise a significant hazard when:

- The area covered by placed materials exceeds 10,000m² or when,
- the height of the tip expressed as highest and lowest elevation exceeds 15m or when,
- the tip is placed on ground sloping at more than 1 in 12 or when,
- other factors indicate adverse conditions.

The *proformas* in Appendix 2 of this handbook include typical 'other factors' that may need to be considered. As implied previously, placed spoil or backfill may be used for restoring quarry faces for example as buttresses; this material comprises a tip and might constitute a significant hazard. The proformas allow for some prioritisation of the hazards. In practice it is commonly found that scores of less than 5 or 6 are not truly significant when a geotechnical assessment (the next step in designing or checking the design of a slope) is made. For example a tip covering more than 10,000m² but of limited height on level ground may be quite secure. An experienced geotechnical engineer should be able to advise if this is so, without the time and cost of a full assessment.

If however a geotechnical engineer is of the opinion that a significant stability hazard exists, a geotechnical assessment as defined in Regulation 33 is required to check that failure will not occur and/or to advise on the redesign and construction/management of the slope. Details of the investigation and steps required in a geotechnical assessment are given in Schedule 1 of the Regulations including the site survey, site investigation, the preparation of cross sections and plans, a listing of assumptions before stability analyses and the findings of these analyses. Final designs coming out of the analyses and requirements during and after construction must be set out. The report of the geotechnical specialist must incorporate simple conclusions as to the safety of what is proposed or excavated/built, whether and what remedial works are required and must be signed (with professional qualifications) by the specialist who obviously thereafter has legal liabilities in respect of his work. The quarry operator also has a duty to ensure that all necessary works are undertaken by a specified date and that in the first place all available information is given to the geotechnical specialist. Regulations 34 and 37, set out together with Regulation 33, impose additional obligations on the quarry operator relating to repeat assessments and notifications to the HSE. SME operators should also be aware that the mineral owners (if not the operator), have a duty to disclose all information relevant to safety at the site and an obligation not to require unsafe working limits.

The cost of a geotechnical assessment can represent a significant expense to an SME operator. In the author's experience this can range from an initial geotechnical assessment costing about £2,000 to as much as £20,000 or even more for very large quarries. The cost depends on the extent of investigations and testing required that may include drilling boreholes *etc.*, the range of different quarry slope settings that need to be considered and the perceived risks with the proposed slopes. However most SME quarries are relatively small and in many cases further detailed investigations are not needed or not required beyond those for geological purposes. Geotechnical specialists should be aware that when tendering for such work they should always have full disclosure of all information. This should include previous reports from the owner and operator of the quarry. The collection of insufficient information from site investigations (often with severely limited budgets) is no defence in the event of inadequate design and any subsequent legal action. It should be appreciated that short term quarry slope design may not be appropriate for long term slopes and various quarry after-uses.

Coming out of the slope design is a requirement to ensure that adequate rules are in place for the proper construction of the slope which are safe and that appropriate precautions are taken to avoid any accidents (Regulation 31). The design should specify the height of benches and the overall slope, the width of benches, the method of excavation and ground preparation, the provision of drainage, the direction of working, safety arrangements and the means of dealing with matters such as rockfall. Regulations 13 and 16 relate to barriers that all quarries, regardless of size, have to use. These are needed to prevent vehicles and persons accidentally falling from bench crests or haul roads. They may also be needed to protect those on benches and haul roads from being struck by falling debris. Failure to provide adequate edge protection commonly results in improvement notices or working prohibitions if they are not in place when the HSE visits a site.

The Quarries Regulations are seen by some operators as an additional burden and expense (see below), but this is not the way that the more responsible see the new requirements. Safety during operations is paramount; it can be equally important in the after-use of quarries. Small quarries should in general have less by way of problems and costs; the exceptions are where very large excavations remain from earlier or very long-term workings.

Operators and owners

Mineral owners who let their mineral deposits to operators have a major interest in maximising mineral recovery since royalty payments usually include a payment in some form for tonnage or volume removed within a given period. There are some landlords who require a payment for mineral not recovered at the end of quarrying to promote maximum recovery. Since planning permission goes with the land the owner is the person entitled to work the land for minerals. He also has obligations that are set out in Regulation 5 of the Quarries Regulations. Guidance to this regulation published by the HSE indicates that the 'owner' retaining some control over the way the quarry is worked may still have duties under the Health and Safety at Work Act 1974. Working limits have to be set so that mineral can be recovered safely. Not all mineral owners are aware of their duties in this respect and some regard final slopes that are not vertical as irresponsible and wasteful on the part of the operator! Operators should be aware that owners cannot legally enforce a breach of safety legislation.

Nevertheless operators also have very different opinions of how final slopes should be left. Some want to recover the last available tonne of rock even if it involves bench removal and they may have little or no interest in quarry after-use. Others see safety and sustainable final slopes as one of the means by which a satisfactory operation in planning and landscape terms may facilitate extensions or development of quarries elsewhere.

From the quarry visits there is a growing appreciation of the need to prevent or control large scale slope failures, but there is still little interest in controlling rockfall unless there has been a particular problem with previous dangerous occurrences or accidents. Many operators visited during the study had not even considered the desirability of scaling rock faces immediately after blasting; operators should be aware that if accidents occur due to rockfall they can be prosecuted for having breached Regulation 30 by having failed to construct, operate and maintain secure slopes. Many mineral leases have no provision for requiring the scaling of faces, removing hazardous potential falls of ground or ensuring long-term stability. Most have vague, anodine clauses requiring the excavation of safe slopes without specifying the way in which final faces are to be left or providing for the rectification of any problems after the completion of quarrying.

It is thought that the limited interest that some owners or operators show is a consequence of their lack of interest or involvement in the end-use of the quarry excavation. Interest is however often increased where the MPAs have expressed concerns about stability or landscape issues and quarry extensions are under review.

MPAs and planning guidance

MPAs were contacted in the principal quarrying areas in England and asked to complete a questionnaire in respect of the relative importance of issues relating to secure and sustainable final quarry slopes. There was a 78% response and the findings were as follows on a scale of 1 (least important) to 5 (most important). The 8 characteristics considered were:-

	Characteristic	Importance Ranking Average	Range
i.	Stability of final slope	4.3	3-5
ii.	Form of final slope (benching arrangements height)	3.5	2-5
iii.	Visual impact	4.4	3-5
iv.	Restoration standard	4.3	3-5
v.	Suitability for intended after-use	4.5	3-5
vi.	Compliance with planning conditions	4.2	2-5
vii.	Safe access	3.2	2-4
viii.	Maximised mineral recovery	2.0	1-3

MPAs clearly regard suitability for after-use as important together with visual impact, stability of final slopes and restoration standard. Many of the quarries visited were recommended as good or poor examples of final slopes. Visual impact and suitability for intended after-use were seen as specific concerns by many MPAs and emphasised in accompanying correspondence.

A general policy approach set out in Government advice and to be followed by MPAs is a presumption in favour of the restoration of mineral workings. MPG1 (General Considerations) states "*Land taken for mineral extraction or the depositing of mineral wastes should be reclaimed to a standard suitable for a beneficial after-use as soon as possible.*" There are a number of reasons for this policy:

- To prevent dereliction.
- To minimise environmental effects of mineral workings.
- To promote long term safety.
- To help achieve some of the targets set in the UK Biodiversity Action Plan [78].
- To avoid/reduce fly-tipping.

In 2000 the Department of the Environment, Transport and the Regions published Mineral Planning Guidance Note 5 (MPG5) dealing with Stability in Surface Mineral Workings and Tips [22]. Stability had previously been considered a priority in Planning Policy Guidance Note 14 (1990) and MPG5 sought to integrate recent research and the implications of the Quarries Regulations 1999 to ensure that operations and restoration, as well as surrounding land, were not adversely affected by instability and that at the end of mineral workings, slopes remain safe with due account being taken of potential instability in future land-uses [18]. The MPG states that final perimeter slopes and restoration proposals have land-use implications that need to be considered by MPAs. Quarry companies making planning applications and involved in the review of old permissions need to provide MPAs with an assessment and design of perimeter or final slopes to enable any potential for adverse effects due to instability to be assessed and minimised. Three options were noted:

i. Design the slopes in detail before submitting a planning application.

ii. Design the slopes in detail after the granting of planning permission as part of a landscaping restoration scheme to be agreed before excavation commences.

iii. Design the slopes before reaching the final limits of working.

Since different sites have different ground conditions and local concerns the appropriate timing of design from a planning perspective will vary. Final slopes need by law to be designed before their excavation commences; the law allows for modification if necessary on safety grounds. In planning terms it would be most unwise to leave detailed slope design until permission is granted if there is a potential hazard of significance to neighbouring land, or people, or if the extent of the mineral resource is in dispute. Firm guidance is given regardless of timing that restoration/landscaping schemes should be accompanied by a (geotechnical) design report by a competent person that demonstrates that the perimeter remaining after restoration will remain stable. Local planning authorities are also advised to consider stability in relation to development in or near old quarries.

Unfortunately few MPAs have staff with appropriate geotechnical skills although many have landscape professionals. It is important that advice is obtained to ensure an adequate assessment has been made especially in critical locations of public safety or where instability could damage views into the quarry.

English Nature

English Nature (previously the Nature Conservancy Council) has a responsibility for earth science (geology and geomorphology) conservation. In Britain the identification of important Earth heritage sites started after the Second World War (under the National Parks and Access to the Countryside Act 1949 and the Wildlife and Countryside Act 1981). In 1977 the Nature Conservancy Council began a systematic review of key sites as a means of protecting specific features of scientific interest. A Site of Special Scientific Interest (SSSI) is a legal designation of a site that in the opinion of English Nature is of special scientific interest for its flora, fauna, geological or geomorphological features. There are two types of SSSI *viz* integrity sites and exposure sites. Active and disused quarries may comprise exposure SSSIs in whole or part. The landowner and the local planning authority will have been notified with citations, maps and other documentation if a particular quarry is a geological SSSI. Designation as a SSSI does not override existing planning permissions but may have implications for quarry after-use or for new planning proposals in relation to an existing quarry.

The rationale behind the selection of conservation sites is beyond the scope of this handbook but two practical criteria have been that there should be a minimum of duplication of interest between sites and that it should be possible to conserve the site. The justification for conserving sites of geological interest includes their value to professional researchers and earth scientists in industry and to students and staff in higher and further education [55]. There is no obligation on the owner or operator of a quarry to permit public access to a geological SSSI within a quarry. However experience shows that many owners of quarries with SSSIs are sympathetic to geological conservation. Owner's concerns are varied and may include:

- Safety at the site.
- Safe access to the site.
- Privacy and confidentiality regarding site operations.
- Disruption of site works or loss of staff time.

Owners and operators can find benefit in visits by primary and secondary schools and interest groups in fostering improved relations with the local community. Often it is found that whilst a whole quarry is listed as a geological SSSI, in practice only a small section of the SSSI such as a short length of a particular face is of prime interest. As noted below, it is appropriate to ensure that slopes of particular geological interest are made quite secure and are sustainable with long term access.

At present, and in the context of the Quarries Regulations, the authors are of the opinion that operators of active quarries should not permit direct access to rock or soil faces unless there is no risk whatsoever of rockfall or soil collapse onto those examining the face. Obviously faces 2 to 5m high and with safe slopes should be suitable for close examination. If there is any doubt, then that quarry face should only be for inspection from an appropriate distance. It should be noted that several large firms of quarry operators (not SMEs) have Health and Safety rules preventing even their own geologists from approaching closer than a prescribed distance to a quarry face (typically 5m).

For closed quarries the obligations lie with the owner. He may permit access, but it is impossible for him to remove liability or transfer it to the visitor if an accident occurs. Signage and the use of indemnity forms do not remove the obligation on the owner to take all reasonable steps to prevent accidents to those who may visit an SSSI in a closed quarry. A review of a fatal accident near a rock slope indicates that in respect of rockfall an owner owes the same duty to trespassers as to approved visitors and that prevention measures within an owner's means should always be in place [57].

English Nature is aware of these hazards in active and closed quarries and has published information on the steps that may be taken to reduce the risks for those visiting a site [56]. Obviously it is desirable to keep faces open. A survey at 111 active and closed quarries with SSSIs showed that 53% had inaccessible faces due to instability and 41% were inaccessible because of the height or steepness of the face (often the same faces) [55] [56]. Dangers from instability were recognised as primarily rockfall having been caused by blasting, weathering and stress relief influenced by natural discontinuities such as bedding, jointing or faulting. Instability was not so marked at weak rock/soil quarries. Steep high slopes were also regarded as being inaccessible due to rockfall risk. A listing of the methods that might be used to enhance suspect slopes were given in a 1991 handbook of earth science conservation techniques [56]. These included rock-face stabilisation with recommendations on:

- Scaling down rock faces.
- Reprofiling of faces including pre-split blasting.
- Rock bolts and meshing.
- Fencing of unstable areas.
- Placing fill for access (and support).
- Underpinning gabions and masonry pillars.
- Drainage.
- Shot blasting and chemical treatment of rock faces.
- Preservation by burial.

Some of the methods quoted by English Nature are quite appropriate, but the application of these methods today needs very careful consideration in terms of the safety of those doing the work. For example a risk assessment is needed prior to scaling from either the crest or the toe of a slope. Scaling with operations from the top of a quarry face must be under the direction of a competent banksman after the clearance of an adequate danger zone where loose material may fall. The banksman must ensure no danger of fall of the backhoe used. If working takes place from below it is best done on the blast pile following initial ground preparation, with a debris rock trap hollow in front of the machine. The backhoe should always have a long reach and stand at a horizontal angle to the face not directly in front. The machine distance to face height ratio should be 1:1 or 1:<1 and the backhoe boom should not be steeper than 45°. Rock pillars should be removed from above, not below (see Table 6.1).

Similarly the reprofiling of faces is not to be undertaken lightly. The drilling of blast holes to reduce bench heights and to flatten face angles also needs prior risk assessments and is regulated by legislation [14] [41]. Protective barriers or harnesses are needed when drilling blast holes above slopes and if new benches require clearance, that work has to be done with appropriate edge protection. As noted elsewhere the excavation method greatly affects whether loose rock is left on faces.

It is recognised that special measures such as netting, fencing and the use of gabions or masonry to support very special faces or features may be appropriate, but this is not the normal sort of measure that quarry operators should consider. Quarry faces should not now be excavated and quarries should not be operated in a manner that requires such measures unless specified in planning conditions. However fill can be very useful in buttressing excavated faces and allowing access to secure faces against which it has been placed (provided the fill itself is made secure by proper compaction and drainage).

Oddly English Nature has expressed approval of restoration blasting as a method of restoring quarry faces. Elsewhere in this handbook there is much concern with restoration blasting since unless carefully scaled at the time of the work rockfall remains a serious hazard. This is the case in most places where it has been attempted to date. In addition the blast pile is typically very flat and does not replicate natural landforms. Finally access to the rock slopes across the blast piles can be quite hazardous unless finer sized materials have been used to backfill the large hollows in the blasted rock pile.

Obviously there can be a conflict of interest in backfilling spoil against a face or excavating a face so that re-vegetation occurs. Landscape and geological conservation can be in conflict. Pre-split wall blasting has a most unnatural/artificial appearance even when partially covered by lichen. However the authors have significant experience of designing new quarries and quarry extensions where most rock faces will be buried but where small carefully selected exposures of bedrock, safely accessible with low bench faces and adequate safety fencing can be used as a method of enhancing a planning application. A thoughtful approach to the provision of safe access on an existing quarry can often help with a future planning application elsewhere.

Other parties

Over the last decade there has been increased public awareness of, as well as scare mongering, over environmental matters. The geology that is visible in quarries is now seen not just as being of interest to academia, researchers or industrial professionals but to local interest groups and those with geological leisure pursuits. Exposures of rock are seen as beneficial in terms of biodiversity. Local authorities are increasingly eager to establish a network of geological sites of less importance than the national SSSIs. These sites of local significance are recognised by institutions such as the Geologists Association and local geological or natural history societies. Local groups are frequently set up with the assistance of local authorities to select and steward these RIGS or Regionally Important Geological and Geomorphological Sites. These sites have no statutory status, but through group pressure some sites can be incorporated into local structure plans.

At their best such local interest groups can assist owners (who may include operators) in improving access to old quarry faces in closed parts of working sites; unfortunately some individuals in RIGS groups seek to visit quarry faces without appreciating the safety risks that may be inherent in unrestricted visits. Nevertheless the authors are of the opinion that controlled access can assist the quarrying industry in several ways including improving the understanding of the need for aggregates even in the context of recycling. Not least it helps when more robust action has to be taken against unauthorised access to quarry faces by individuals, often fossil hunters, which unfortunately is still quite widespread.

Introduction

This chapter is concerned with the nature of the rocks that are quarried by SMEs to produce aggregate and with the physical characteristics of the quarries worked. There are approximately 1100 aggregate quarries in England of which about 60% are worked by SMEs.

These quarries principally work 4 types of geological deposit, sands and gravels, limestones (including dolomites) sandstones (including quartzites) and igneous and metamorphic rocks. The breakdown of the different sectors in terms of the number of quarries and annual output [9] [10] is as follows:

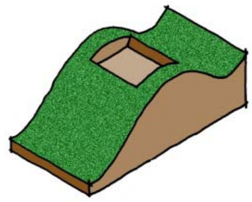
Rock Type	All quarries		SME quarries
	Number	Output Mt	Number
Igneous and Metamorphic	46	23	17
Sandstones	191	20	168
Limestones	271	79	170
Sand and gravel	605	63	321

Not all these quarries produce only aggregates. A significant number of sandstone and limestone quarries produce dimension stone *i.e.* building, flooring and walling stone and to greater or lesser extent aggregate production is a bi-product of this activity. Together the combined mineral production from all four rock types is about 185Mt per annum. This comprises mainly aggregates, but also some material for other uses.

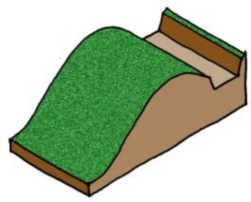
The SME quarries vary considerably in their size, face heights and other physical characteristics. Many of these quarries are quite shallow workings especially sand and gravel excavations and some limestone operations. However a minority are larger, deeper workings at times with faces up to 50 to 100m high. There are four basic types of quarries and various combinations of these types *viz.*

Hillside quarries

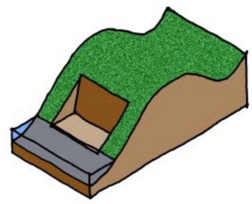
Hilltop quarries



Valley bottom workings



Coastal quarries



Combinations

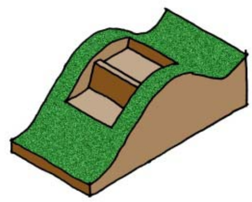


Fig. 3.1 Types of Quarry Settings

Quarries are commonly worked in series of levels or benches. This is because a system of benching is used as a flexible means of adjusting overall slope angles. The dimensions of benches their height and width can be used to control the overall angle of the slope of the quarry sidewalls. Benches are usually less than 15m in England since bench heights are influenced by the Quarries Regulations 1999 (Regulation 32 and ACoP) and bench face angles commonly range from 75 to 90° depending in part on the way in which the bench has been blasted and excavated. Often bench faces break back near the crest as a result of blast damage or ground conditions. Ideally bench faces should be scaled to reduce the risk of break back and rockfall onto those working below. The width of benches to a large extent controls the overall angle of final or ultimate slope. If the benches are wider the overall slope is flatter and *vice versa*. The width of benches is an important element in design of the final slope since it controls the use of that bench in respect of:

- Access.
- Potential for blasting as part of restoration.
- Feasibility of backfilling for restoration.
- Ability to trap rockfall in the context of development at lower levels.

Some quarries regard benching as an optional item or something that can be removed towards the end of working, but these are potentially hazardous activities and can result in warnings or prohibition notices from the Quarries Inspectorate given the risks to those in the quarry.

Hillside Quarries

Fig. 3.2 Hillside Quarry in Limestone

These are probably the oldest forms of quarries being an extension of the removal of rock from natural outcrops. In their basic form they comprise a three sided notch into a hillside. One face is the highest and the other two are endwalls with a triangular shape. Such quarries may be long linear structures and if they follow a particular bed of rock they may form contour-like features. If such quarries are circular in plan there may be a single entrance and a fourth set of faces may lie opposite the highest face. Frequently these quarries may be deepened.

Hillside quarries may therefore have quite high faces on one side and this can present a prominent feature on a natural hillside, valley side or escarpment. Hence the treatment of this face may become important in terms of visual impact in the context of the surrounding countryside. It is also important that these slopes are secure and can be managed so that post-quarrying derogation does not occur. Instability in these quarries can be most intrusive in the landscape. Frequently overburden and waste from the mineral workings may be used to screen the workings on their lower side but such structures seldom fully conceal the larger quarry face.

Hilltop Quarries

Fig. 3.3 Hilltop Quarry in Limestone

These are probably the least intrusive forms of mineral working since there are usually few views into the excavation. Basically it comprises an excavation in high ground ideally leaving no externally visible faces. This may be difficult to achieve since often the processing of aggregates takes place outwith the rim of the quarry and there is commonly the need for an access ramp that requires exposed faces. Sometimes these quarries are regarded as sinking or open-cut type quarries since they are not necessarily located on hilltops but in flatter or gently undulating ground.

The crests of all faces are seldom at the same level. In these circumstances it may become necessary to consider local screening or to address the problem by treating the high exposed face. Typically only the upper 1 or 2 benches may be visible from outside the quarry; these may require specific attention to avoid adverse visual impacts from more distant locations.

Valley bottom workings

Fig. 3.4 Valley Bottom Quarry in Limestone

Typically, but not exclusively, these comprise sand and gravel operations and in essence are visible from the nearby valley sides and hill tops depending on the local relief. The opportunity for screening may be quite limited unless the workings are narrow or linear in plan. Fortunately many such workings are wet or close to the water table so long term secure and sustainable slopes are not an issue. Excavated slopes that were formed at the limits of the workings may become banks or beaches to lakes *etc*. established after the completion of the mineral extraction.

Coastal Quarries

Fig. 3.5 Coastal Quarry in Metasediments

These are a special form of hillside quarry located close to the sea, or where the sea may have been in the past. They can either result in a linear excavation parallel to the coast or bay-like features. In such a setting viewed obliquely along the coast, across a bay or from the sea, benching tends to be anomalous unless that part of the coast has prominent raised beaches remaining from the geological past.

Many coastal cliffs in England are prone to collapse partly due to erosion and wave action. However instability and degradation of coastal quarry slopes is less desirable since the faces are not necessarily immediately adjacent to the sea. Much thought needs to be given to the final treatment of these faces especially if coastal development housing, marinas, footpaths *etc*. are intended following after the end of quarrying.

Combinations

Fig. 3.6 Hilltop and Hillside Quarry in Limestone

Pure hillside or hilltop quarries are unusual. Often quarries comprise a combination of settings especially in rolling countryside or when the quarry workings are very extensive so that public roads or footpaths cross the workings as well as running around the margins. In these circumstances the final treatment of the slopes can be as prominent and as important as that in hillside quarries.

Quarry boundaries

It should be noted that the illustrations of the above types of quarry (Fig.3.1) are somewhat idealised. The boundary shape and configuration of a working depends to a very large degree on the land ownership or control by the SME at the time a planning application was made. Often this can give rise to unusual, irregular shapes that appear abrupt or unnatural (Fig.6.19). It is often found that noses or promontories of rock that protrude out of a quarry face are prone to tension cracking and rockfall (owing to stress relief). Attempts should be made at the planning stage to acquire the necessary land or to modify the design to introduce less sharp features.

Stability and different rock types

In each of the above types of quarry the stability and sustainability of the final slopes are closely related. As noted in the introduction sustainability is broadly interpreted to imply fitting in with the local landscape and requiring minimal maintenance or a prescribed and achievable maintenance programme. Clearly unstable slopes do not comply with this definition unless instability is inherent in the local setting and acceptable in terms of health and safety and visual impact. Instability, even in the form of rockfall is rarely acceptable for many of the more common after-uses of land within and around quarries.

The 4 rock types found in English aggregate quarries are all represented in the different types of quarry settings noted above.

Igneous and metamorphic aggregate quarries may be of hilltop/sinking cut type operations as for example in some SME operations in South West England or hillside quarries as in parts of Northern England. A number of coastal quarries are also present in these rocks in South West England. Granite and dolerite sills represent two different types of igneous rock often worked in dissimilar ways and frequently having characteristic features that are reflected in different forms of instability or rockfall (see Figs. 3.7 and 3.8). These rocks are commonly strong and massive but movements can occur along jointing especially if this is inclined towards the excavation or steeply into the quarry face when toppling movements may arise. Some of the more basic igneous rocks can be deeply altered and prone to weathering.

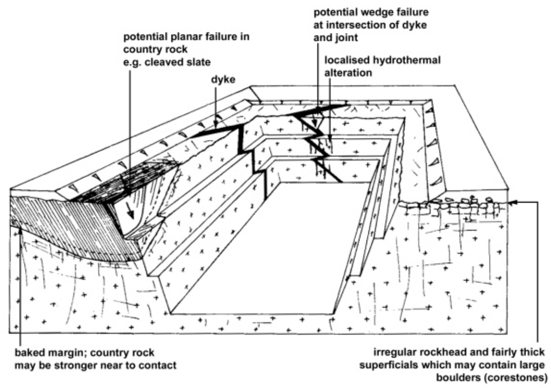


Fig. 3.7 Large igneous intrusion - typical setting

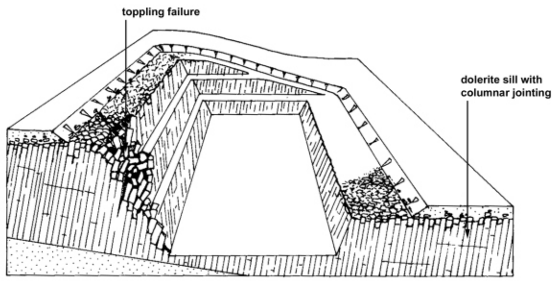


Fig. 3.8 Small igneous deposit - typical setting

Sandstones and quartzites are extensively worked from the Millstone Grit and the Coal Measures in Northern and Central England whilst Devonian sandstones and Permian sandstones are worked in some parts of Central and South Western England. Frequently these quarries recover both building stones and aggregate. Fig. 3.9 shows some of the features that may be found in sandstone quarries a number of which are more than 50m deep. With sandstones their strength is often variable and some weak horizons may be interbedded with much stronger more massive strata. Movements can occur along bedding planes or current (false) bedding that may be steeply inclined to the larger scale bedding features. A variety of instability including bedding plane slides and toppling features may occur in these quarries. These slopes can be excavated to quite steep gradients, but experience indicates that rockfall is an important hazard in sandstone quarries. Research has shown that there has been a disproportionately high incidence of serious and fatal accidents due to rockfall in these quarries.

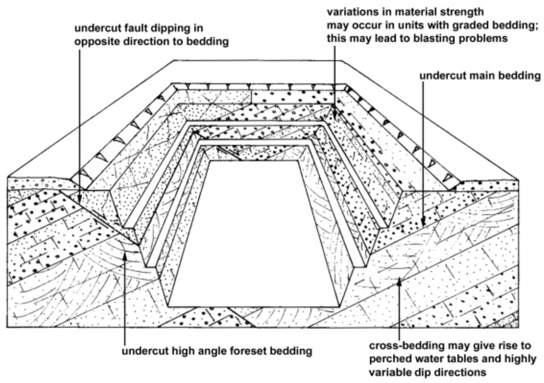


Fig. 3.9 Sandstone and quartzite deposit - typical setting

Limestones and dolomites are the most frequently worked rock amongst SME firms producing aggregates. Jurassic, Permian, Carboniferous, Devonian and Silurian limestones are all worked by SMEs and the workings, as for sandstones, are often combined aggregate and dimension stone operations. The working depths are similarly variable and include a number of quarries of more than 60 to 70m in depth. Some typical settings are illustrated (see Fig. 3.10). Features that may influence stability include solution widened joints and bedding planes and most importantly interbedded clay bands or shale beds that may dominate stability. These are found in most limestones and are particularly important where bedding is inclined at more than 7 to 8°. The clay bands may also act to perch groundwater so that seepage is likely to occur in final slopes left in some limestone quarries, with erosion of the clay band or shale bed that restricts groundwater flow. Permian and Jurassic limestones undermined by coal workings can be significantly broken with deep tension gashes and in consequence prone to toppling failures. Cambering or down-warping of strata towards clay bottomed valleys can also be prominent causes of similar problems in Jurassic limestones.

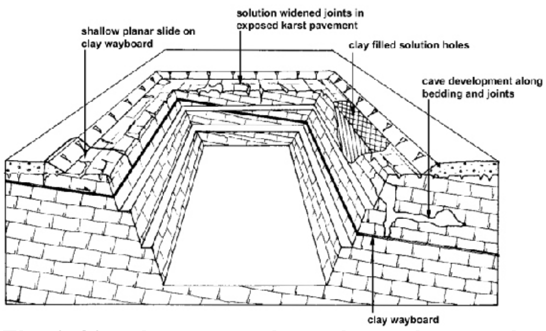


Fig. 3.10 Limestone deposit - typical setting

Sand and gravel workings comprise by far the largest number of SME mineral operations. They range from river gravels and glacial sands and gravels to strata based sands and gravels.

River gravels are usually old terraces close to or above current river levels having been left after the down-cutting of the water course. Principally such workings are found in Southern and Eastern England (*e.g.* River Thames and its tributaries) although river gravels are worked in the Midlands (Rivers Severn and Trent) and further north. These workings are generally wet in part and frequently final slopes comprise the banks to ponds and lakes so usually are of limited relevance to this study.

Glacial sands and gravels commonly lie above the water table and in places bedrock may form the foundation materials to final slopes. Such sites are chiefly in Eastern and Northern England where final slopes may be up to 15 to 20m high. The underlying strata may determine whether the toe of the final slope is dry or flooded.

Strata based sands and gravels are found mainly in the Middle Jurassic or younger strata (*e.g.* Folkestone Beds in Kent and Sussex and the Coral Rag in Oxfordshire) but sometimes from the Permo Trias where loose gravels may be present as in parts of Southwestern England and the Midlands. Some of these quarries may be 40 to 60m in depth. These quarries comprising essentially loose materials can be excavated to steeper slopes if as in places there is a weak cementation or locking of the sands or gravels. Typically the Folkestone Beds and some Permo Trias gravels can be excavated to slopes of 60 to 70° but such slopes can collapse with little warning especially if affected by rising water or discharges of water over the quarry face. Erosion of such final slopes can be quite extensive especially if there is no control of seepage from above.

Fig. 3.11 Steep Slopes in the Folkestone Beds

Introduction

This chapter briefly notes the general methods that can be used when considering the nature of the final slopes. In line with MPG7 the authors are in sympathy with the statement quoted in Chapter 1 of this handbook that … "*wherever possible and safe to do so the natural gradients and rock features of the surroundings should be imitated when forming new screening banks … and final slopes.*" This is the fundamental principle of landform replication; the first part of this chapter sets out the general approach to this in slope design.

The remainder of the chapter deals with the more general methods of forming and completing final slopes including ground preparation and excavation, buttressing and the use of waste materials and the use of vegetation as a screen and a landscape feature. The general geotechnical considerations are summarised in Chapter 5 and more specific examples of slope treatment are given in Chapter 6.

Landform replication

Over recent years, interest has been expressed in respect of landform replication or simulation in which mineral workings are so organised that their final form is consistent with landforms found in the local landscape. To some extent landscape architects have also sought to apply elements of the natural landscape to their restoration designs, but this is not normally based on strict morphometric analysis as employed in geomorphology.

Landforms vary substantially according to rock type, rock structure and the weathering, erosion and deposition processes which have operated in the past. Landform replication aims, by a combination of excavation and the placement of waste material, to reshape bulk mineral workings to these natural landforms. Conceptually, the re-creation of landforms that are typical of an area should facilitate the re-establishment of land-uses that are consistent with those in the neighbourhood. These landform assemblages are then replicated in the working and reshaping of the ultimate quarry slopes as far as is practical and consistent with reasonable quarry practice. The approach differs significantly from routine landscape architecture which, whilst employing elements of natural landforms, may apply other, more subjective criteria and approaches often, for example, relying on the use of planting to obscure benches and other residual features of workings.

In terms of quarrying practice the objective of landform replication is to obtain the steepest, secure ultimate slopes that are commensurate with the local or immediate geomorphology and consistent with economic mineral recovery. Natural landforms generally reflect one or more of the following: rock type; structural aspects, such as bedding, faulting and jointing in the local rock mass; the presence of superficial materials, such as glacial till or peat; and the effects of surface processes, including glacial erosion and deposition and fluvial and coastal erosion/deposition.

The steepest secure slopes which replicate the local geomorpholgical setting are preferred, since this maximises the potential mineral reserves for a given area. It is particularly important to assess the range of slope angles that obtain in nature. The proportions of each slope facet or element within the overall slopes from hill top to valley bottom are of particular interest and need to be determined *e.g.* the proportion of the slope height that comprises the convex, concave and linear slope facets.

Strictly whenever landform replication is considered to be appropriate it should be based on geomorphological mapping that, *inter alia,* identifies characteristic features of slopes in plan, such as linearity, sinuosity and regularity [67] [69].

Landform replication does not merely consist of the simulation of a single quarry slope around a feasible working area but, if possible, involves the development of a total replicated landform in plan. This concept was developed in a study of conceptual methods of forming whole new landform features such as valleys and modified escarpments and spurs as part of large-scale mineral workings. Fig.4.1 sets out the basic concepts; in practice, matters such as valley width, width-to-depth ratios, sinuosity and the form of the valley head are relevant items, since rigid geometric shapes rarely occur in nature. Different landforms apply to different rock types.

The question then arises as to where landform replication should be used? In view of the cost and reserve implications in some situations it is reasonable to restrict application to key areas where the techniques are most appropriate.

These might include: visually intrusive sections of quarries, especially in hillside settings where screening is not practicable and quarry slopes in particularly sensitive areas such as Areas of Outstanding Natural Beauty (AONB) when extensions to existing workings are sought. Locations where screening techniques would be intrusive may also be considered together with locations where the nature of the intended after-use is an important issue.

It is unlikely, except in critical areas or settings or where landform replication forms the basis for a particular after-use, that extensive lengths or even full slope heights would necessarily require the use of replication techniques in all parts of a quarry. In many quarries such as hill-top workings, only small areas of the ultimate quarry slope are visible from beyond the quarry limits and many of these can be satisfactorily screened by planting and/or using overburden, *etc.* that requires out-of-pit disposal in any event. However in some places of great sensitivity it is reasonable to plan an entire quarry layout to conform to the principle of replication rather than simulation (see Fig.4.2).

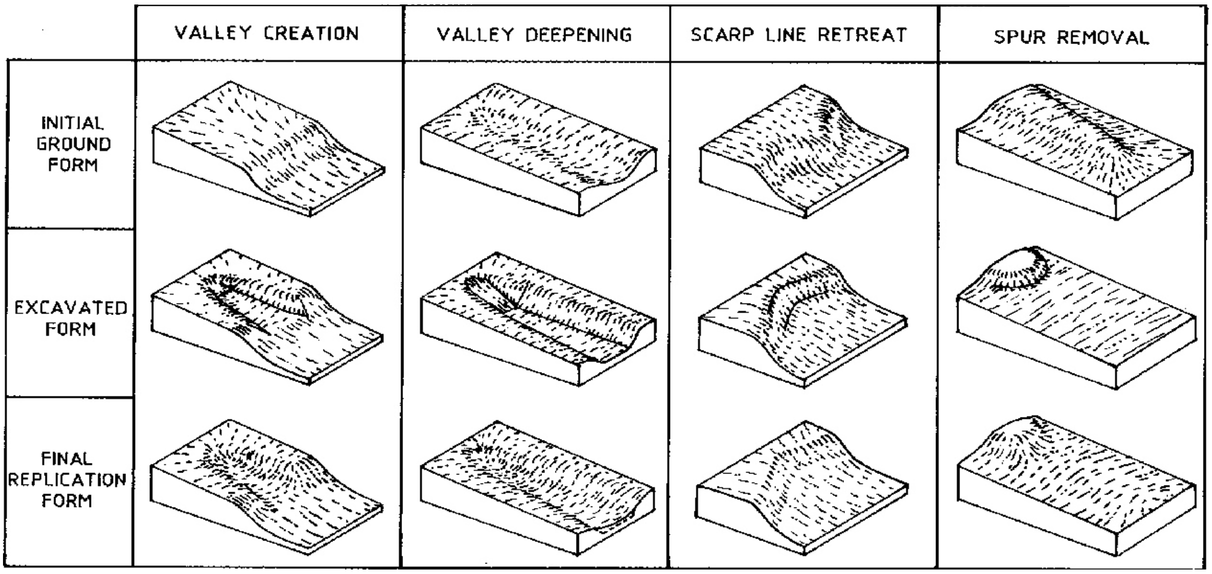


Fig. 4.1 Concepts of landform replication

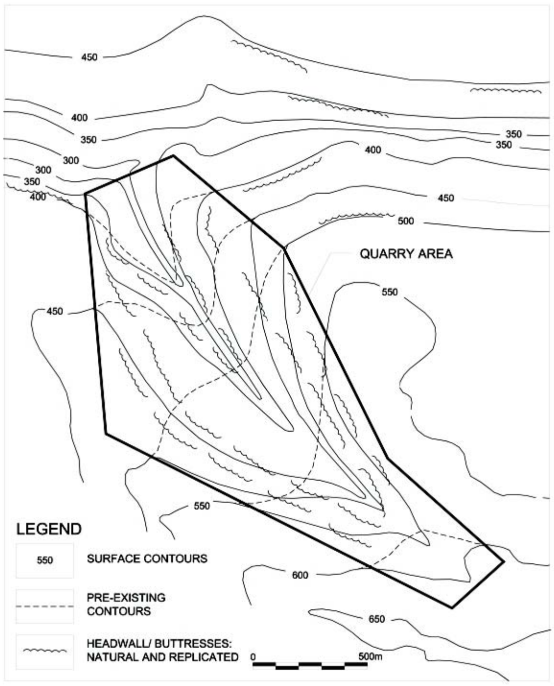


Fig. 4.2 Conceptual landform replication for a quarry in limestone country [67]

Restoration blasting

A special form of landform replication (or simulation) is restoration blasting. Restoration blasting was conceived as a means of replicating a number of daleside landforms that characterise Carboniferous limestone areas of parts of Derbyshire and Yorkshire [28] [36]. These are stepped features that incorporate steep rock outcrops in headwalls (continuous sub-vertical slopes) and buttresses (noses of stronger rock protruding from the headwall) (see Fig.4.3). Beneath these features are angle of repose (*c* 35°) scree slopes variously covered in vegetation. A Department of the Environment funded project investigated restoration in a series of trials between 1988 and 1993 [36]. A subsequent audit of these trials showed that headwalls and especially the buttresses were prone to rockfall and that the blast pile that represented the scree slope (Fig.4.4) was unnaturally flat (20 to 25°) [33] [37] [25]. The blasting results in a dispersed low angle blast pile.

The authors are not impressed with this form of landform replication which is more akin to simulation and has subsequently been attempted in highly unsuitable and irrelevant quarry settings in igneous rocks and steeply inclined Limestones *etc*. where such features do not naturally exist. More work remains to demonstrate its future use in multi-bench situations, but as presently used it requires very flat wasteful overall slopes (*c* 1 in 2 or flatter). Restoration blasting projects to date all appear to have been adversely affected by the need to re-vegetate a blast pile rather than forming a more suitable plant growing medium by using other materials.

Fig. 4.3 Natural limestone daleside with headwall buttresses and scree

Fig. 4.4 Headwall buttresses and scree slope formed by blasting. Note damage to buttresses

A recent scheme has been noted [70] [72] in which quarry waste is backfilled on benches in a secure scheme of working to allow for angle of repose spoil/secure slopes and very limited linear sections of headwall (Fig.4.5). The quarry visits revealed other sites where this approach had also been implemented.

No limestone quarry acceptable to mineral planning authorities (MPAs) has yet been designed with replicated daleside slopes as part of a full valley feature. However, such a quarry would appear to be feasible in practice. The form shown in Fig. 4.2 is that for a notional side valley quarry based on natural slopes. Unfortunately to date such slopes have not been achieved in restoration blasting trials. More work needs to be done to explore the valley forms which may be employed in other locations and to examine either the feasibility of generating steeper blast piles to simulate more closely scree and/or the incorporation of overburden and quarry discards into the 'scree'.

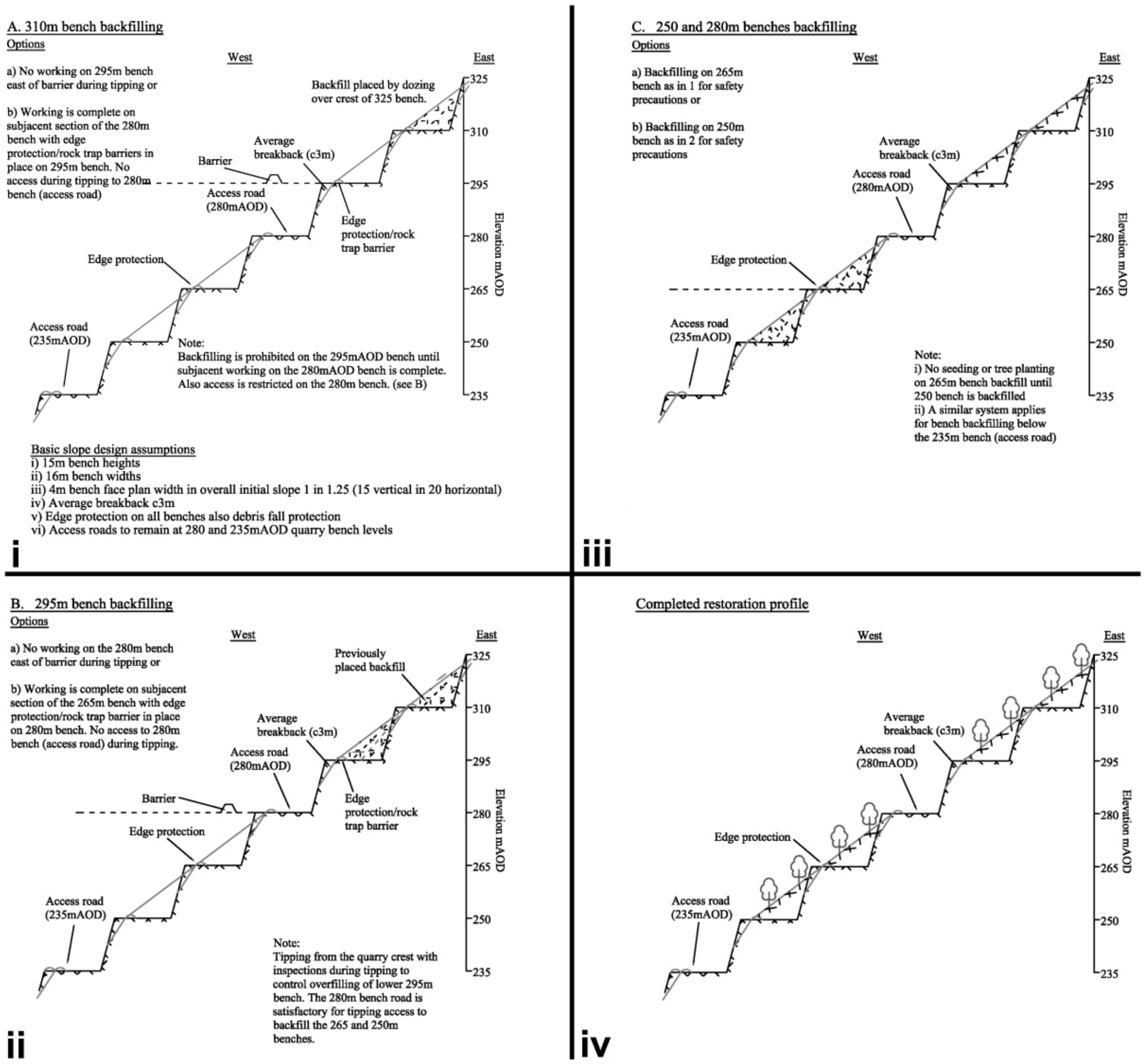


Fig. 4.5 Stages in the backfilling of benches with spoil

Fig. 4.6 Example of largely buttressed quarry benching

Other landform replication models

The most interesting, but most complex potential landform replication concepts involved the replication of features such as corries and U-shaped valleys which are characteristic of previously glaciated areas. These natural landforms are generally found in stronger rocks many of which are appropriate for aggregate production [73].

Subject to geotechnical constraints, hard-rock quarries replicating natural features in glacial areas could have steeper slopes of 40 to 50°, which for most practical purposes are the steepest feasible overall slopes in most quarry operations. Hence, these slopes should not generally give difficulties with reserves; however, the need for benching limits the extent to which replication rather than simulation is feasible. Further work is required to explore the full range of landforms which might be used in new quarries and major quarry extensions (*e.g.* differently shaped valley sides, escarpments *etc*.) and to examine the means by which the need for final benching may be reduced or removed. Finally, methods of more closely replicating the smaller-scale irregularities and roughnesses which ultimately comprise the natural landform need to be considered and the whole approach studied in relation to re-vegetation (see Chapter 6).

During the visits a number of trials were noted, some more successful than others. However the authors consider that landform replication remains in its infancy; much more remains to be done especially in the full range of settings where sandstones, limestones and igneous rocks are worked.

Ground preparation and excavation

Most SME aggregate quarries are worked with blasting as the method of ground preparation. The exceptions are sand and gravel operations and a small number of quarries mainly in thinly bedded limestones where pneumatic rock breakers are used.

Blasting is used to obtain rock in sizes that are readily handled by loading, transport and crushing equipment. Most operators attempt to balance crushing costs against blasting costs to achieve some measure of optimisation. This can be obtained in the operations by varying the number and size (diameter) of blast holes to optimise the size of material in the blast pile whilst also ensuring the permissible level of vibrations from blasting are not exceeded.

Blasting breaks rock by generating tensile stresses that exceed the tensile strength of the rock mass. Attrition of material is also caused by blocks clashing together as they are displaced by the gas pressures from the explosion. Production blasts are designed to allow for a series of millisecond delays between the firing of each blast hole (or a group of blast holes) so that free faces are formed in a logical sequence and to avoid synchronised firing of several blast holes at a time (to reduce the risk of excessive vibrations). Stresses from the shock waves have the greatest effect between the blast hole and the face *i.e.* in the area required for aggregate production. They tend to have less effect behind the blast hole away from a free face. However, gas pressures act in all directions and although they contribute to rock breakage in front of the blast hole they can also lift and open rock blocks and discontinuities (bedding and jointing *etc*.) as well as new fractures generated in the blast. In consequence the faces remaining after blasting can be loose with open joints and a propensity for rockfall unless the face is scaled.

Fig. 4.7 Loose final faces resulting from production blasting

All quarries are now required to adhere to the blasting practices required by the Quarries Regulations 1999 (that follow the 1991 Control of Explosives Regulations). These require blasts to be designed to avoid fly rock and to closely match the loading of blast holes to the profile of the face, the alignment of the blast hole and consequential burden (see Quarries Regulations 1999 ACoP paras. 195 to 198 and Appendix 2). This should result in reasonably uniform faces with no overhangs although these still tend to remain from the section of quarry faces that contained stemming rather than explosives (*i.e.* the uppermost 2 to 3m).

In many quarries inclined blast holes are used routinely. For production blasts the blast holes may be inclined from the vertical by up to 15°; the inclination should be based on the inclination of jointing in the rock face. If as happens at times the jointing is vertical then vertical blast holes are appropriate giving very steep bench faces. Near vertical bench faces are generally of only limited consequence in such a situation since rockfall is not projected forward of the toe by an inclined face. However final faces should be treated differently. Since it represents a very small proportion of the total volume of rock, charge loads can be reduced in the last two rows in front of the final face to limit face damage; thought should be given using the face inclination likely to give minimum undercutting of natural discontinuities.

Pre-split blasting is used to produce faces with minimal damage. Low charges are used to generate a split between closely spaced blast holes (typically 1 to 2m separation). The split is opened up by gas pressures and the cracking is preferentially developed by the existence of the adjacent boreholes. Pre-split blasts are fired instantaneously before the rock in front of the pre-split line is blasted. Unfortunately pre-split faces do not look natural and commonly show regular blast hole markings on the remaining face. It should be remembered that pre-split blasting is used to reduce rockfall; it does *not* prevent slippage that relates to adverse geological structures (see Chapter 6).

Fig. 4.8 Pre-split faces (near) and production blasted faces (beyond)

Blast piles are usually directly loaded so there should be no need to excavate the remaining rock faces using either a face shovel or backhoe. Long reach backhoes can, and in many places should, be used to scale or clear remaining loose material from the faces; especially final faces. Unfortunately in spite of advice to do so routinely, this procedure is still seldom in regular use.

Direct excavation (without ground preparation) with appropriately sized equipment is used in some situations (*e.g.* thinly bedded limestone). If face shovels are used bed separation can occur due to the loosening of the face above the penetration point of the bucket teeth. This can promote rockfall and is most unwise and potentially a significant hazard if the face is being dug by an excavator with a reach that does not extend to the crest of the bench being formed. Cleaner faces can be formed using either backhoes or a breaker prior to excavation.

Fig. 4.9 Loose final faces excavated by face shovel

It should also be noted that face angles in un-blasted rock relate to the equipment used. Face shovels are inflexible and commonly result in some undercutting; backhoes are invariably more flexible and may be used to dress slopes to much flatter angles.

Waste materials

As implied above the final treatment of quarry slopes is often assisted by, and at times may rely upon, the use of quarrying waste or spoil. Typical applications include enhancement of soils for restoration on benches using fine discards, provision of edge protection and rockfall traps, buttressing of faces by on-bench banks or bunds of spoil and large scale backfilling against a final face to provide a secure final slope in spoil *etc*. as well as comprising part of a scheme of landform replication.

In all quarry development and design it is necessary to carefully estimate both the volume (and tonnage) of recoverable mineral and the volume of different types of waste (non-mineral). Some of this waste such as top and subsoil is specifically set aside for restoration often being placed in screening banks at the outset of quarrying to restrict views into the workings *etc*. However there are other forms of quarry waste that are sometimes neglected or inadequately assessed. These include:

- Overburden beneath the subsoil and above the recoverable mineral (rock or sand and gravel).
- Interburden *i.e.* non-mineral material within the main mineral such as clays or shales interbedded with limestones or sandstones.
- Processing waste from scalping, screening and/or washing crushed or as dug mineral.
- Waste mineral *i.e.* substandard, non-saleable material commonly weathered rock or gravels with excess clay fines.

The quantities of these different wastes should be estimated with as much precision as possible using information from borehole records, trial pits, trial mineral processing and laboratory testing. Often there can be changes beyond the control of the operator such as the impact of the Aggregates Levy on the marketability of low-grade aggregates. In the authors' experience SME firms commonly under-, rather than over-, estimate the volumes of waste and sometimes pay little regard to when waste arises in the quarrying operations. For example if a quarry working takes place entirely from the top down rather than by lateral extension, there may be a high proportion of waste excavation in the early stages of working. This is due to overburden and weathered rock *etc*. lying near the surface. A more uniform or phased production often results from lateral extensions with waste production spread over a longer period.

One of the key issues in the use of spoil in the treatment of final slopes is timing. When is the spoil available and when are the final slopes available for restoration? Often restoration is seen as a late stage activity although there is sometimes a requirement to restore or treat high faces quite early in a quarrying operation. To a large extent the restoration of quarry faces depends on the phasing of mineral recovery. A quarry that progressively works in one direction or moves in a rotating fashion means that progressive establishment of final faces is possible thereby spreading restoration costs *etc*. A sinking quarry can only restore the uppermost slopes when excavations have progressed to the second or third bench below the crest.

It should be recognised that quarry wastes can be quite variable in their engineering properties.

Clays and silts have to be used carefully to avoid forming oversteep slopes. Adequate surface drainage and under-drainage may be needed. As noted previously, placed waste is a tip and requires proper design to ensure safety. A proper assessment needs to be made of the volumes of spoil required for specific restoration including the treatment of final slopes. It is often best to draw up two independent inventories of waste quantities; the first for given periods or phases of working and the second balancing inventories of where and when wastes will be used, put to an in-pit or out-of-pit stockpile or used for general backfilling.

SME owners or operators may need to seek advice on this part of a quarry design to ensure how much spoil and of what quality is available for buttressing or for landform replication of final slopes. It is emphasised that this can only be attempted with a good 3 dimensional quarry survey and reasonable grounds for assessing the yields of waste from different parts of the excavation and from processing activities [2].

Vegetation and Planting

In addition to the physical re-shaping of the quarry through blasting and tipping, planting can offer a comprehensive restoration solution.

Planting as a general technique provides six principal benefits:

- Integration with surrounding landscape.
- Visual screening.
- Ecological value.
- Microclimatic amelioration.
- Commercial value (agriculture, forestry *etc*).
- Erosion control.

While creating a sympathetic, long term landform is the most important technique in restoration, implementing a sympathetic planting scheme comes a close second. The benefits of a holistic approach cannot be overstated. Similarly, it is important to understand *why* the natural and human-influenced surrounding landcover has evolved. It is not simply a matter of choosing local tree species. Where are they found in relation to slopes or crags? How large are local copses? How are they managed?

Quarries evolve over time and so, by definition, implementation of planting schemes is progressive. However, there is a big difference between piecemeal and phased restoration. There are numerous benefits to the development of a phased comprehensive restoration plan including planting. These benefits include money saving through efficiency, shorter fencing lengths, effective management and the use of cheaper smaller original plants. A comprehensive plan can distribute planting in order to have maximum effect while allowing maximum flexibility of after use.

MPG7 The Reclamation of Mineral Workings lists best suited species for growing on different types of soils associated with a wide range of quarries [21] (see Table 4.1).

Ensuring Successful Planting

Unfortunately, planting, especially in the early years, requires maintenance, management and replacements. There are ten main reasons why planting in quarries fails and they are all avoidable or capable of substantial minimisation; they are described briefly below:

- **Planting fails through lack of water**
  Choose the right species; plant at the smallest size possible; ensure adequate soil depth and structure; include water-retaining products; consider orientation to sun; provide irrigation.

- **Planting fails through drowning**
  Choose the right species; ensure adequate soil depth; break up sub-strata/subsoils; provide drainage; avoid directing water to planted areas; dig adequately sized tree pits; avoid tree pits in homogenous clay.

- **Planting fails through wind damage**
  Avoid moist exposed areas; select species; plant as small as possible; provide wind shelter tubing; fence areas; plant shelter belt species on windward side; use appropriately sized stakes and ties; inspect stakes and ties regularly.

Mining operation	Type of overburden	Texture	Major limitations for tree establishment	Best suited species
Jurassic and Permian Limestone	Thin calcareous soils over limestone rock	Clay loam, silty day loam, sandy clay loam.	High pH restricts species choice; soil droughtiness due to stoniness; N deficiency; risk of lime-induced chlorosis.	Italian alder, Corsican pine, Norway maple, Sycamore, Poplar.
Carboniferous Limestone	Drift: till in N England, silty drift in Midlands; some thinner calcareous soils in parts of S Pennines.	Dominantly clayey till, silty clay loam in Midlands.	Heavy textures lead to winter waterlogging and summer drought; liability to compaction; silty drift particularly erodible; N deficiency.	Alders, Birch, Japanese larch, Corsican pine, Willow.
Clay/Shales	Till covered in many places.	Dominantly clayey, though lighter textured material does occur.	Heavy textures lead to winter waterlogging and summer drought; liaibility to compaction; N deficiency.	Alders, Corsican Pine, Japanese larch, Birch, Willow.
Plateau Gravels	Stony sandy or loamy soil.	Sandy loam, loamy sand.	Droughtiness; stoniness; low pH; N, P deficiencies.	Scots Pine, Alders, Birch, Corsican Pine.
River Terrace Gravels	Variable thickness and quality.	Very variable.	High groundwater levels in flood plain areas, may have low pH (pyritic soils); other limitations depend on texture and stoniness of soil making material.	Corsican Pine, Alders, Birch, Willow.
China Clay	Variable. Ranging from coarse sand to silt. Generally tipped separately.	Sand, silt.	Pronounced droughtiness; low pH; N, P, K, Mg deficiencies.	Alders, Corsican Pine, Maritime Pine, Sycamore, Sitka Spruce.
Igneous	Gritty drift, often with peat surface.	Sandy silt loam, sandy loam.	Low pH, P deficiency, pioneer species.	Alders, and others.

Table 4.1 MPG7 Plant species list

- **Planting fails through frost damage**
  Select species; provide tubing; provide shelter species; provide fencing; avoid frost pockets and areas with minimal sunlight; plant on slopes.

- **Planting fails through lack of nutrients**
  Test soils before use; add fertilisers to planting mix; select tolerant species; undertake regular application of fertilisers; remove competing vegetation.

- **Planting fails through disease**
  Select species; assess disease in surrounding area; buy stock from quality nurseries; inspect regularly; spray where necessary.

- **Planting fails through smothering**
  Inspect and weed regularly; provide tree spats (weed suppression mats) around base, or mulch; avoid invasive species; prune large species.

- **Planting fails through damage from animals**
  Fence areas appropriately for rabbits, stock, deer *etc*; control vermin; provide plant tubes or guards.

- **Planting fails through human damage**
  Fence areas; concentrate planting; inspect regularly; direct public away from planted areas; plant on hard-to-access areas; plant robust species.

- **Planting occurs in wrong season**
  Follow standard nursery guidelines avoiding the growing season.

It is emphasised that planting should only take place where it is safe to do so and not where or when rockfall might jeopardise the safety of those concerned.

Vegetation Growth

The advantage of planting as a restoration technique is that it grows and contributes increasingly to the reclamation scheme and to its integration into the wider landscape. Planting should always be viewed not just as a mitigation technique to screen the negative elements but as a positive contribution to the landscape in the longer term.

Conclusions

Final slope treatment can be quite varied and there is no one solution to achieving a secure final slope. Chapters 5 and 6 below set out some of the criteria to be addressed and the details that can be considered when dealing with the different slopes.

It is not suggested that SMEs need to attempt all the measures set out in this and succeeding chapters but they might benefit from the consideration of the options that exist. Above all these should be driven by the intended after-use of the quarry.

Introduction

As noted in previous chapters stability and safety are important in the final or ultimate quarry slopes for three reasons. Firstly since those excavating and recovering aggregate raw materials need to be safe, secondly the slope needs to be fit for intended future after-uses and thirdly it needs to fit into the local landscape. Although all quarry slopes have to be excavated safely and in accordance with the Quarries Regulations 1999 (see Chapter 2) some operators and owners have a less than concerned approach to final land use. This is unfortunate since after-uses can often greatly enhance the value of a site and assist the mineral operator with further planning applications. The list of possible after-uses or after-use options is growing (see Tables 5.1 and 5.2). The security of the final slopes is important since it may affect:

- Location and development of structures or land uses in the quarry bottom.
- Access into the quarry bottom.
- Stability of land beyond the quarry crest, not necessarily in the same ownership.
- Visual impact of the final quarry face.

If material is likely to fall from a quarry face it may affect mineral working at lower levels and constrain development at the toe of the slope or behind the crest for many tens of metres. It should be appreciated that the owner of the land above and behind a slope has a right of support of his land and the owner of the slope has a duty, established in case law, in this regard. It is always desirable to own land behind a quarry slope so that risks of movement can be handled and prevented without threats of litigation. Permanent and long-term solutions to ensuring secure slopes avoid subsequent remedial works that can be difficult and costly if not properly handled at the time of quarrying. Similarly a quarry operator seeking to continue his business should be aware that instability in some settings can damage the landscape. The originator of the 'blot on the landscape' may have future quarrying proposals considered very carefully!

Fig. 5.1 Neighbouring landowners (and road users!) have the right to support

Table 5.1 Possible after-uses incorporating water

W1	Water supply/reservoirs
W2	Sailing/marinas/harbours
W3	Power boating
W4	Rowing
W5	Model boating
W6	Swimming
W7	Fishing
W8	Park
W9	Conservation/wildlife habitat
W10	Fishery
W11	Industrial cooling (convection and spray)
W12	Pumped storage (power generation)
W13	Watercourse management/supplement
W14	Water treatment/storm management (near highways *etc.*)

Fig. 5.2 Water sports afteruse of a quarry

Table 5.2 Possible dry restoration after-uses

D1	Landfills, inert and putrescible
D2	Co-disposal PFA(low + high pH)
D3	Industrial and special landfills
D4	Arable/pasture (open agriculture)
D5	Horticulture (including hothouses *etc.*)
D6	Forestry
D7	Sport and recreation (open)
D8	Sport and recreation (covered)
D9	Car parking
D10	Storage
D11	Industrial/commercial (B1, B2, B3)
D12	Leisure (cf Centre Parcs)
D13	Retail (cf Bluewater)
D14	Education/tourism (cf Earth Centre/Eden)
D15	Residential
D16	Hotel
D17	Golf course
D18	Campus development (hospital, college, barracks, prison)
D19	Rail interchange (intermodal)
D20	Scientific (astronomy/satellite)
D21	Technical (materials/vehicle/structure testing)
D22	Energy (solar, geothermal, wind, heat exchange, landfill gas, methane, coal, wood, nuclear)
D23	Museums -quarrying, stoneworking *etc.*
D24	Nature conservation including geological SSSIs and RIGSs
D25	Sculpture park (art within a sculptural landform)

Factors affecting slope stability

It is not proposed to detail all the factors or constraints that influence whether a quarry slope will be secure but a brief outline is appropriate. The main constraints on the stability and behaviour of rock and soil slopes are:

- Position and properties of structural features *e.g.* bedding planes, joints, faults *etc.*
- Properties of intact rock and soils *e.g.* shear strength.
- Groundwater conditions *e.g.* water pressures within or behind the slopes.
- Operational controls *e.g.* slope geometry height, face angle, benching arrangements and excavation technique.

Together these constraints determine where ground movements occur and their size, (including lateral and vertical extent of these movements). These constraints operate at all faces in a developing quarry, but there are a few constraints that may occur at the limits of final slopes that are not present everywhere. Where a major fault or an abrupt change in the rock type (due to an unconformity or a deep glacial channel) or strata dip suddenly increases, these may have determined the limits of working. Such changes may also represent an adverse change in the ground conditions so that in some settings the final slopes may require more investigation and even different slopes from those used elsewhere in the quarry.

Types of slope failure

The identification of the potential modes of slope failure is a pre-requisite of slope design and management. The mode and scale of failure within a slope is dictated by both the natural and man-made factors noted above. These factors combine to give rise to many potential failure mechanisms, but the majority have common elements which allow their classification into a few major groups. Table 5.3 summarises their general characteristics and notes typical settings and failure characteristics; this chapter gives more details of the main mechanisms and the problems associated with rockfall.

Surface water or groundwater often has an adverse effect on slope stability. Water that gains access to a potentially unstable slope *e.g.* along failure surfaces, release planes or tension cracks at the rear of the slope will act to promote instability. Further, water may cause weathering along release surfaces to reduce material strength, which also acts to reduce stability. The management of water on and behind slopes is extremely important in long-term secure slope design.

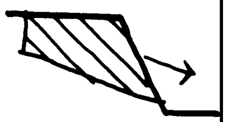
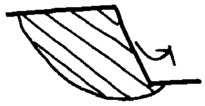
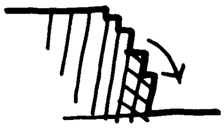
Mode of failure	Geotechnical setting	Critical factors promoting instability	Typical working situation
 Transitional	All rock slopes with adversely oriented planar discontinuities. (*i.e.* faults, joints and bedding planes with a component of dip into the excavation)	(i) Unfavourable face orientation (ii) Undercutting of critical discontinuities (iii) High water pressures (iv) Daylighting of critical discontinuities	All rock face excavations (even in very strong strata)
 Rotational	(i) High faces in weak rocks (ii) Thick superficial cover (iii) Spoil piles (iv) buttressing materials	(i) Crest loading (ii) Toe excavation (iii) High water pressures	Overburden stripping in weak material
 Toppling / Columar collapse	Over steep faces with highly inclined discontinuities which act as release planes	(i) Over steep faces (ii) (iii) High water pressures in rear discontinuities (iv) Closely spaced discontinuities steeply dipping into face (v) Undermining	Steeply excavated rock faces
 Rockfall	Occurs in most over steep rock slopes. Individual blocks or small volumes of material based on unfavourably inclined release surfaces	(i) Over steep faces leading to undercutting of individual blocks (ii) Degradation of ground due to weathering (iii) High water pressures (iv) Freeze-thaw cycle (v) Overblasting	Steeply excavated rock faces

Table 5.3 General failure modes and settings

Failure within a rock mass

Large scale instability (greater than 5 to 10,000m³) is not common in quarries but it does occur and was reported to have taken place at some time in 20% of the quarries visited during this study. The most common is controlled by translational sliding along pre-existing planar structural features (such as bedding, jointing and faults) where the release surface is undercut by the excavation. Translational sliding may be sub-divided depending on the number of surfaces delineating the failure surfaces as follows:

- Planar failure (including slab failures).
- Biplanar and multiplanar failures (shearing along two or more planes in the same direction).
- Wedge failure (shearing along mutually inclined and intersecting faces).

Toppling failures and columnar like collapses arise basically from a non-sliding mechanism. They are generally small (less than 10,000m³) where they occur in aggregate quarries but exceptionally can be much larger.

A detailed discussion of the underlying causes of these potential failure mechanisms and of approaches to the assessment of stability is beyond the scope of this handbook. Further information is available elsewhere [30] [31] [44] [50]. The steps in appraising the need for a detailed geotechnical assessment and what that assessment comprises is given in Regulation 32 of the Quarries Regulations. Fig. 5.3 summarises the principal modes of slope failure and these characteristics are noted in Table 5.3.

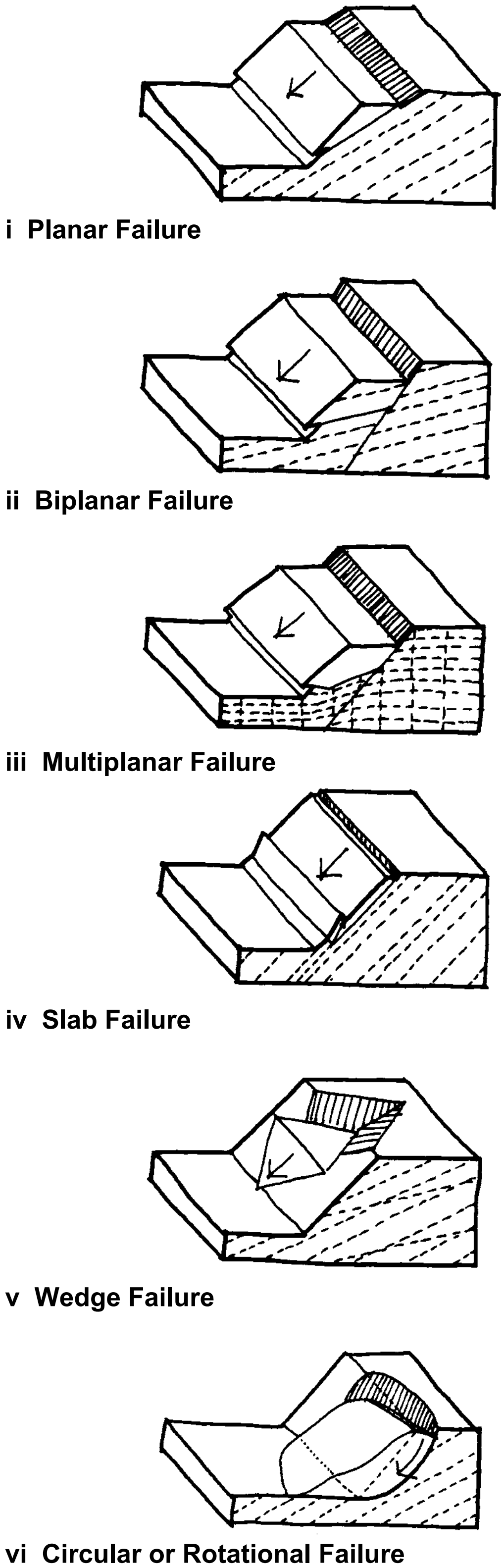


Fig. 5.3 General modes of slope failure

Planar failure

Planar failure basically involves sliding of rock mass along a single planar surface usually inclined towards the excavation. Such failures may lead to the loss of benches and even failure beyond a quarry crest (see Figs. 5.4 & 5.5)

Typically these failures occur when the excavation of the bench face undercuts the plane on which sliding takes place. Typical settings where large single, (>5 to 10,000m³), planar failures are found include:

- Limestone quarries; bedding plane failures usually associated with intercalated soil-type materials (including thin clay bands of sedimentary or weathered volcanic origin).
- Sandstones and quartzite quarries; bedding plane failures often associated with interbedded mudstone horizons.

Fig. 5.4 Planar instability in a limestone quarry resulting from undercutting of bedding by excavation

These failures are concentrated on the up-dip or low wall side of these quarries especially where benching or faulting leads to the undercutting of bedding. Movements are known on strata dips as low as 7 to 8°. Planar failures are not, however, restricted to sedimentary rocks and can also occur on faults, cleavage planes and joints in all rock types. Sliding can also occur along several sub-parallel planes at the same time; sometimes these surfaces may be stepped.

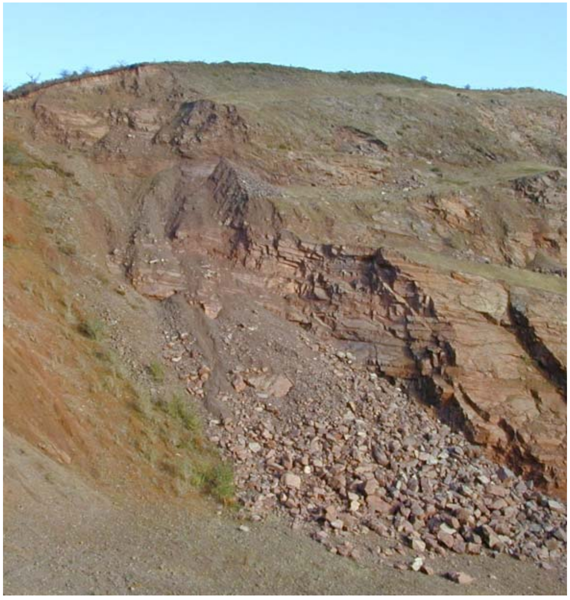
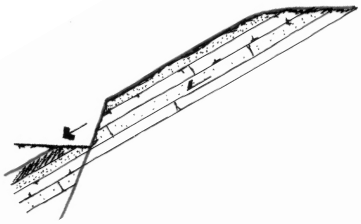
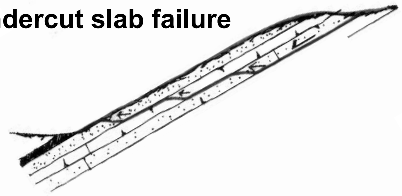


Fig. 5.5 Planar instability along bedding and loss of quarry crest and access to lower benches

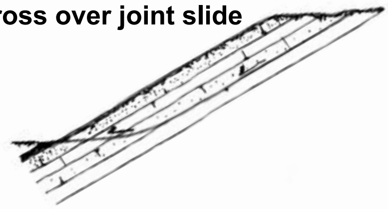
Slab failure is a special case of translational failure and occurs mostly in thinly stratified or slaty rocks. Slab slides differ from planar and multiplanar modes of instability in that the depth of a failure is small in comparison with its length. Even though an excavation does not undercut a potential failure surface, failure may still occur through breakout or buckling at or near the toe of a slope. The length of slope which may be safely excavated depends on the strength of the rock mass and the water pressures which obtain with increasing depth of excavation. Fig. 5.6 illustrates settings where slab failures could occur [30].



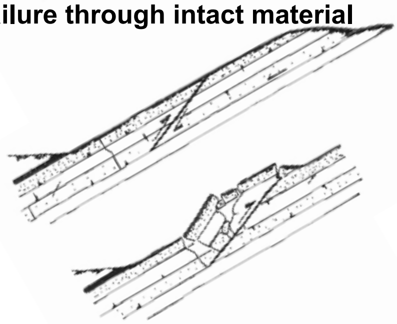
i Undercut slab failure



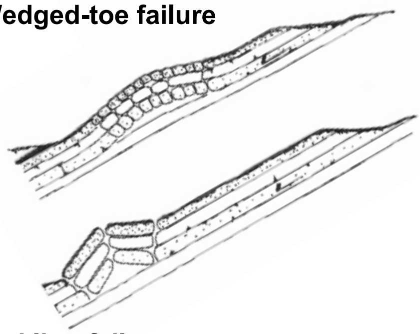
ii Cross over joint slide



iii Failure through intact material



iv Wedged-toe failure



v Buckling failure

Fig. 5.6 Slab type failures

Biplanar and multiplanar failure

Biplanar failures comprise shearing along two planar surfaces of differing orientation. The mechanism of failure may been analysed as an active rear wedge which drives the instability and a passive forward wedge which acts to resist instability. The scale of such failures may vary considerably but can lead to large slope movements. This type of failure should always be considered where faults or other continuous discontinuities are present, particularly where these features delimit the extent of quarry workings. Biplanar failure may also occur within spoil used to buttress unstable rock slopes, especially if this fill is placed on weak materials on the quarry floor and/or high water tables in the spoil are allowed to develop (see Fig. 5.3ii).

Wedge failure

Wedge failure comprises the translational sliding of a mass along the intersection of two or more surfaces inclined towards the excavation. Fig. 5.7 shows a typical wedge failure. These are usually smaller scale instabilities (frequently <100m³) and often comprise localised bench break-back. Wedges may be formed by the intersection of joints with other joints or bedding or faults. The design of a quarry slope should consider the extent of any such break-back in order to ensure that adequate benches remain.

Fig. 5.7 Wedge failure in a magnesian limestone quarry (note continuing unravelling of upper slope)

Toppling failure

Toppling failure results from rotation of a rock block where the centre of gravity of the mass lies in front of its base. As shearing is not the dominant failure mechanism such failures may occur rapidly with little warning. Although less common, toppling and sliding can occur together with extensive movements. Toppling failure depends on the presence of well defined structural features (see Fig. 5.8). Most commonly toppling is small scale and restricted to a single bench and follows blasting induced loosening.

Fig. 5.8 Toppling of blocks in a limestone quarry

Columnar collapse

Columnar collapse comprises the localised failure of a face where scaling has not been attempted and poor excavation practice and stress relief has resulted in a loosened and broken rock mass. Collapse occurs when a columnar or tabular block buckles under its own weight or when undercut by the deterioration of foundation materials such as weak shales. This type of instability was seen in many of the quarries visited, often closely associated with areas of increased rockfall. These collapses are localised but frequently associated with 'noses' left in final faces *e.g.* buttress features formed by restoration blasting (see Figs. 5.9 and 5.10).

Fig. 5.9 Columnar collapse and rockfall in nose left in face in a magnesian limestone quarry

Fig. 5.10 Columnar collapse in basalt workings

Failure through weak materials - rotational or circular failures

Rotational or circular failures frequently occur through oversteepened weak materials with little structural control. A single failure surface is developed which follows a curved or circular path (see Fig. 5.11). These movements may become quite extensive especially in clay-rich overburden or fills. The mechanics and analysis of such failures is covered extensively in soil mechanics textbooks [12].

Fig. 5.11 Rotational failure through saturated superficials overlying clays and sand deposits

These failures may also develop in slopes where the individual blocks are small in comparison with the overall slope, where stronger rock materials are very heavily fractured and through materials of low intact shear strength (such as superficial deposits, sands and gravels or tipped materials). Groundwater pressures and tension cracks filled with water promote such instability especially in materials of low permeability (clays, tills *etc*).

Rockfall

Rockfall refers to the localised dislodgement of relatively small blocks of material from freshly formed and/or degrading, excavated faces and from natural slopes. It differs from slope failure in that it does not result in significant changes in slope geometry. Whilst rockfall involves relatively small volumes and tonnages of rock, its safety implications should not be underestimated. Rockfalls are more likely to occur following heavy rainfall, during frosty periods and from slopes which are south facing and which are subject to greater temperature variations.

Rockfall is the most significant failure mode involving serious injury or fatalities in slope failures in quarries (and also along highways). This is because of its frequency and relative unpredictability. A study of all serious injuries and fatalities resulting from falls of ground in UK hard rock quarries over a 15 year period showed the significance of smaller volume rockfalls over much larger slope failures (see Table 5.4). It accounts for *c.*75% of notifiable slope movements in active quarries; inevitably, the majority of rockfall incidents go unreported and as such it must be emphasised that all excavated slopes have the potential for continued rockfall.

Mass of slope failure (tonnes)	Number of injuries (F– fatal S– serious)	
>10,000	2	(2F 0S)
10,000-1,000	2	(0F 2S)
1,000-100	5	(2F 3S)
100-10	6	(4F 2S)
10-1	4	(0F 4S)
<1	24	(3F 21S)
Not specified	10	(1F 9S)

Table 5.4 Number of fatalities and / or serious injuries with mass of slope failure (UK quarries over a 15 year period) [29]

Many of the settings from which rockfall may develop are small scale versions of the larger slope failure mechanisms. The role of excavation technique in final face formation must also be considered - rockfall is more likely to occur as a consequence of poorly controlled blasting and or excavation techniques which may further loosen the strata and cause the development of localised overhangs or noses (see Figs. 5.9 and 5.12).

Rockfall is a hazard at many geological SSSIs. At present there is no coherent approach to the monitoring of safety at these sites. The system of hazard appraisal for excavated slopes, and rockfall hazard and risk assessment should be implemented at all SSSIs in both current and closed quarries (see Appendix 2). This should be undertaken every 2 to 5 years depending on the frequency of visits. English Nature should adopt a systematic approach to hazard and risk assessment, with clear guidance on the safe proximity of access to quarry faces based on the findings of an ongoing programme of inspections. The present reliance on owners accepting risks and liabilities resulting from fatal or serious injuries due to rockfall is unreasonable if access is to be encouraged.

Fig. 5.12 Differential weathering of interbedded shales with limestone giving rise to overhangs

Approaches to slope design and construction

Secure rock slopes require the elimination or control of the elements contributing to natural and induced instability. The assessment or design of stable final slopes should minimise the requirement for future remedial treatment and maintenance. Attention needs to be given to the local geotechnical conditions and to the use of appropriate excavation techniques to minimise disturbance during excavation.

The re-excavation or re-profiling of a rock slope requires careful preparatory design and works. This usually includes stability assessments of existing final slopes and the design of the proposed final slopes with the design and installation of appropriate drainage measures. Adequate rockfall containment measures and the protection of existing structures may need to be covered. Wherever possible, slopes should be designed to eliminate the potential for future instability thereby precluding the requirement for expensive later stabilisation measures.

Any stability assessment requires the collation of field data. The assessment of large slopes requires the collection of all available information on the geology (structural and lithological), hydrogeology and hydrology and the geotechnical setting. This may in part be derived from a review of existing slopes. In hard rock slopes this usually implies that all potential failure modes should be considered (usually using stereographic analysis) [50]. It should be noted that the mode and magnitude of potential instability will vary around any given excavation. The potential for both translational and circular failures is generally considered using conventional limit equilibrium techniques where the ratio of resisting forces to disturbing forces is computed. This ratio is known as the Factor of Safety (FoS) which is greater than 1.0 if a slope is shown to be stable. The design of restraining measures often addresses the uncertainties in the geotechnical assumptions used in analysis by seeking a suitable FoS greater than 1.0. Various methods of limit equilibrium analysis applicable to hard rock slopes are available [31] [44].

Although highly relevant when considering the likelihood of bedding plane slides *etc.*, such analyses are rarely appropriate for slopes with a rockfall hazard. Loose rock on a face will have a low FoS, but it is not practical or expedient to assess all such rocks. More empirical approaches are used relating to the openness of joints, looseness of rock, previous rockfall incidents and the setting in relation to persons below tend to be used in any assessments (see Appendix 2).

The key matter in the assessment of *rockfall hazard* is to locate the position and characterise the rock face from *which* rockfall may originate. There is a wide range of methodologies for data collection as well as data interpretation. For existing slopes, the collecting of data may include measurement of rockfall volumes near the toe of the slope, remote survey and measurement methods using laser survey and photographic equipment, and for special areas inspection of the face in detail *via* scaffolding, hydraulic lifts *etc*. Such investigations of excavated final faces are only necessary when general methods of handling rockfall such as re-excavation or scaling are not viable and when the situation demands careful attention. In this case, consideration needs to be given to the intended access by quarry staff and others to the face and to the after-uses proposed. It is obviously important if people are likely to be close to slopes or if buildings *etc*. are erected near the rock face. It is important to collect relevant data to identify areas from which rockfall (or larger rock mass failure) may occur. In practice this is often achieved using photographs as working plans to locate and mark (i) areas of loose rock, (ii) excessively open joints, (iii) blocks requiring removal, (iv) zones requiring support or protection. Secure areas should also be positively identified

There are no formal analytical methods for assessing the quantitative risk of rockfall from a rock face akin to the limit equilibrium method for larger rock blocks and rock slopes. Qualitative assessments based on some form of ranking are used, however. Once critical areas from which rocks might fall have been identified, the hazard may be quantified by use of rockfall simulation programs which attempt to simulate the possible rockfall trajectory envelopes through a probabilistic analysis [62]. This is needed when it is necessary to assess how far from the toe of the slope rockfall of different sizes can travel. Although rockfall is usually most concentrated within 5m of the toe of the slope, it frequently falls, rolls or bounces further. From high slopes with debris choked benches and/or with scree at the toe rockfall may travel to 20 to 30m or even further. The *Risk* may then be addressed by considering the period that people or plant *etc*. are present within the danger zone.

Where "noses" are left as a consequence of a change in face orientation *e.g* changes in land or mineral ownership, changes in geology *etc*.
Production of oversteep slopes, especially those without intermediate benches to arrest any falls. Choked benches accentuate the rockfall trajectory envelope.
Slopes with bedding and or joint dipping into the excavation.
Slopes comprising materials which weather at differential rates *e.g* sandstones interbedded with shales.
Slopes affected by undermining (this may cause the opening of pre-exisitng discontinuities).
Where poor excavation technique has resulted in a broken and loosened final face.

Table 5.5 Settings commonly associated with rockfall

Fig. 5.13 Choking of residual bench following face collapse and continued rockfall

Excavation of rock

As noted elsewhere, the method of excavation has a direct bearing on the stability of the final excavated slope. Where relatively low energy forces are imparted to the rock mass, *e.g.* by direct excavation as opposed to blasting, the final slopes can be usually formed so that relatively little remediation and maintenance is needed. However, the method of mechanical excavation must also be considered. More stable slopes with less rockfall are usually generated by excavation or dressing using a backhoe and/or rock breaker as opposed to a front end loader or face shovel which causes a loosening of the rock mass often leading to relatively unstable final faces and many overhangs (see Fig. 5.14).

i Unstable final faces produced by face shovel excavation

ii Stable faces excavated using a backhoe

Fig. 5.14 Different excavation techniques in the same quarry

Blasting can cause considerable damage to final rock slopes that may give rise to many small loose blocks and a high potential for rockfall. Several methods of blasting are used in order to limit instability, however only the pre-split technique appears to eliminate most of the damage to the final face. When correctly designed and implemented, pre-splitting can produce very clean faces with minimum breakback and disturbance although there may be environmental costs in respect to visual impact. The subsequent mucking out operation must be carried out carefully to avoid damage to the pre-split face. Undercut discontinuities will remain a potential hazard in a rock face and are not 'removed' by pre-split blasting.

It is surprising to find the extent to which vertical blast holes are still used in situations where joints are not vertical. In such quarries a 10 or 15° inclination from the vertical would reduce the overhangs that frequently occur with vertical holes. Most of the overhangs that arise from blasts are caused by the failure to break the upper 2 to 3m of the burden owing to the stemming that occupies this section of the blast hole rather than explosive. These overhangs are most marked at any corners of a quarry face including inner corners of noses in plan.

Rockfall containment and protection

The designated after use of a quarry and the location of final slopes dictate the type and scale of any rockfall protection measures that may be necessary. These include:-

- *Slope buttressing* or the placing of quarry waste against a face. This can protect against weathering and prevent undercutting of weaker units which could induce further instability. Positive drainage is also required with such support.

- *Surface protection* such as shotcrete with steel reinforcement or dentition. These may be used to provide reinforcement to shattered zones or aid local bolt reinforcement. This method is rarely used in quarries but often used in rock cuttings along roads.

- *Netting* is a less satisfactory prevention measure since loose material can collect behind the face but it can be useful to protect key structures or roads or access to very important SSSI rock faces.

Containment measures can be effective and may well be more economic than expensive and visually intrusive preventative measures. Fig. 5.15 shows the commonly used containment measures in civil engineering projects. The techniques vary depending on the scale of risk, the size of blocks, the profile of the rock slope *etc.*; they include:

- *Intermediate benches* are common for high permanent quarry slopes and may be an effective means of catching rockfall, particularly in combination with rock traps. The use of a rockhead bench should be considered where overburden in excess of 5m thickness is present. The effect of the bench gradually filling up with debris also needs to be considered.

- *Rock traps* are particularly effective in catching rockfalls along benches or along the toe of a slope provided sufficient room is available. Rock traps may be constructed as an excavated ditch, deformable barriers such as banks of fill or gabion structures, or in exceptional circumstances a tensioned catch fence or wall. The floor of any of these traps may be covered with a layer of uncompacted fill or soils to absorb the energy of falling blocks. The fill should ideally have a reverse gradient to further arrest any rockfall.

- *Catch fences or barriers* are a special form of barrier occupying less space than a more typical bank of fill. These fences may be grouted into the rock slope and possibly further supported with anchored cables. They are a permanent extension of the temporary fencing used on some quarries to protect blast hole drillers and shotfirers.

- *Netting* can be anchored along the top of the slope (and to the face) using galvanised rock dowels and cables; the method is commonly employed for permanent slopes above roads and buildings. The purpose of the mesh is only partly to restrict or stop rockfall but mainly to control it by trapping blocks between the mesh and the rock face thereby reducing the velocity which may cause the rock to move away from the slope onto people and structures.

The useful life of rockfall containment measures will be extended by minimising the amount of rockfall and removing, during dry weather, any blocks which have fallen. Netting usually has a life of 40 to 60 years when galvanised and regularly maintained.

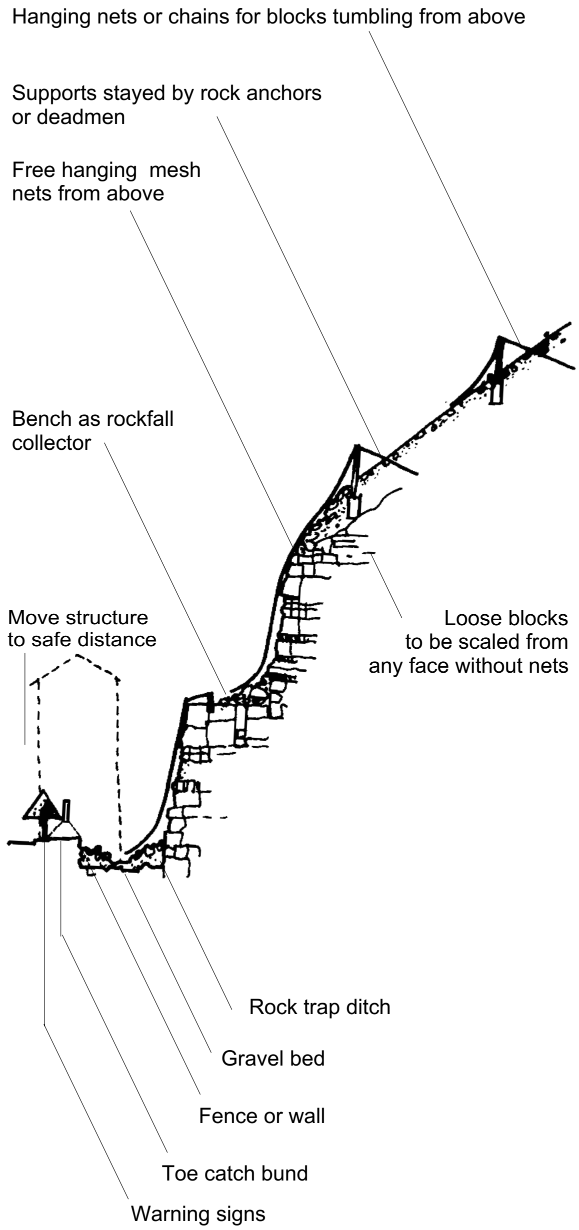


Fig. 5.15 Civil engineering rockfall containment measures [27]

Simple empirical design charts for rock trap ditches for highway cuttings have been developed [60] [44] (see Fig. 5.16). The empirical rock trap design charts may be used as a starting point for catch ditch design. Computer simulation may be used to refine the trap design and its positioning. Planting and fencing to prevent or discourage public access to the toe of slopes is also often employed.

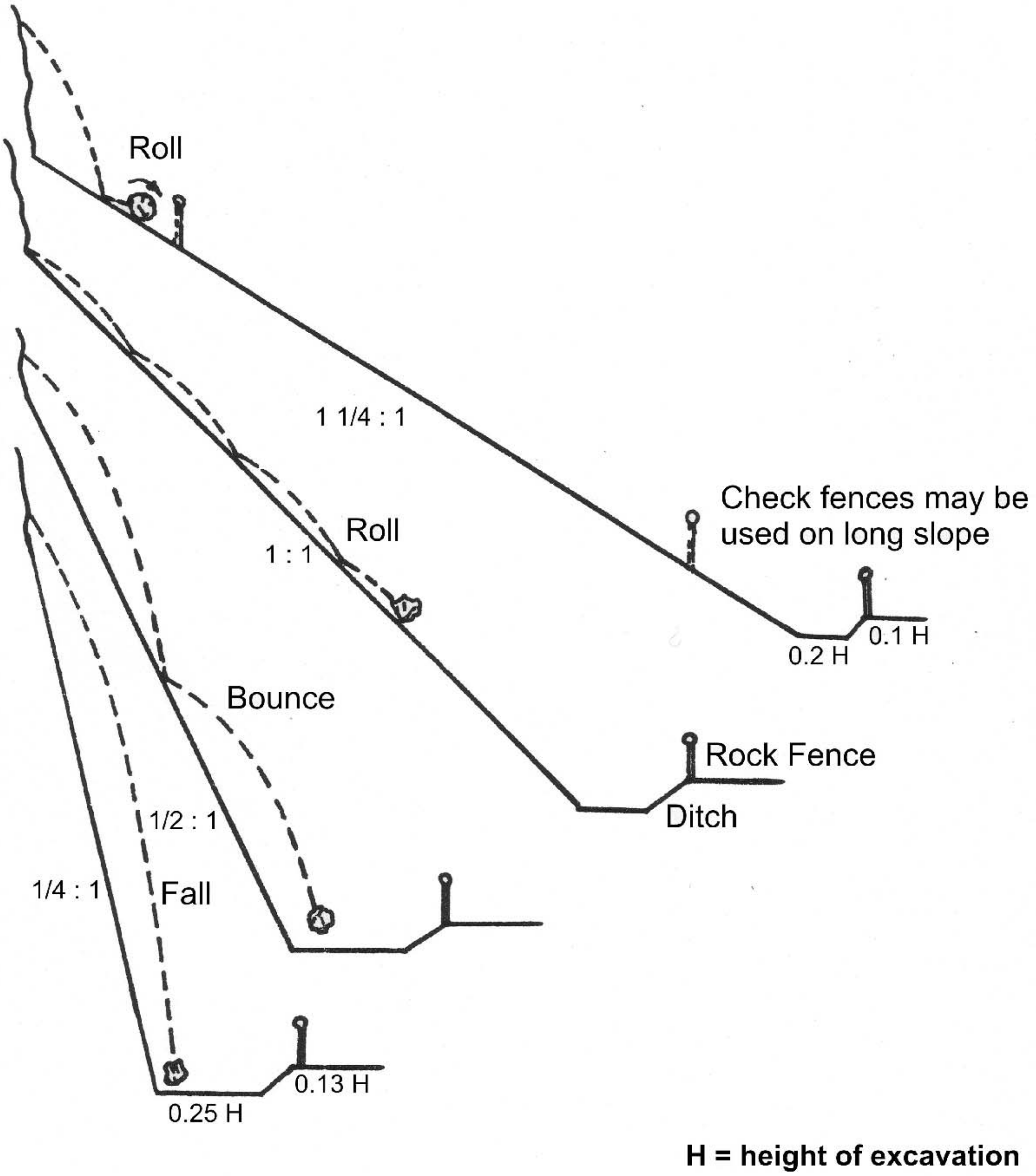


Fig. 5.16 Empirical rockfall protection measure [60] [40]

Drainage control

To avoid localised increases in water pressures within a slope or behind individual blocks or wedges drainage control and diversion measures are critical. Such measures are illustrated in Fig. 5.17 and include:

- Diversion of permanent watercourses and up-slope surface run-off from the crest of the slope. Ditches should be lined with an impermeable material *e.g.* concrete such that infiltration into the slope is avoided.
- Surface run-off from the face should be channelled along intermediate benches and the toe of the slope. Again, impermeable channel linings may be beneficial.
- Intermediate benches should accommodate an appropriate fall for drainage. Any major cracks within the slope should be filled to avoid water infiltration.
- Localised drainage holes within the rock face may be required to control the build up of water pressures within critical areas of the rock slope. Such measures are required to relieve build up of pressures adjacent to aquicludes (such as intercalated clay bands) and behind structural features.
- All drainage measures must be periodically inspected to ensure free flow and integrity of channel linings.

Geotechnical/Stability issues - points to be considered for final quarry slopes

To conclude, the following list sets out 50 general points that should be considered when thinking about final quarry slopes from a geotechnical or stability point of view. They are indicators of good practice. Guidelines to proper design have been referred to elsewhere [30] [32]:

- All quarry slopes, including the final slopes, should be excavated in accordance with the Quarries Regulations 1999.
- The owner of the face of a quarry has a duty to the owner of land behind or in front of that quarry face to ensure the security of the land and the safety of those upon it.
- Whoever designs a quarry slope is legally responsible for any consequences arising out of collapses or falls of ground from that face either below or on the slope or behind the slope.
- All quarry slopes, including final slopes, that require a geotechnical assessment must be surveyed.
- Hazard appraisals of all quarry slopes are required by law, including final faces, and can be done by competent persons with experience in excavating quarry slopes. If a significant hazard is identified in accordance with Regulation 32, it is

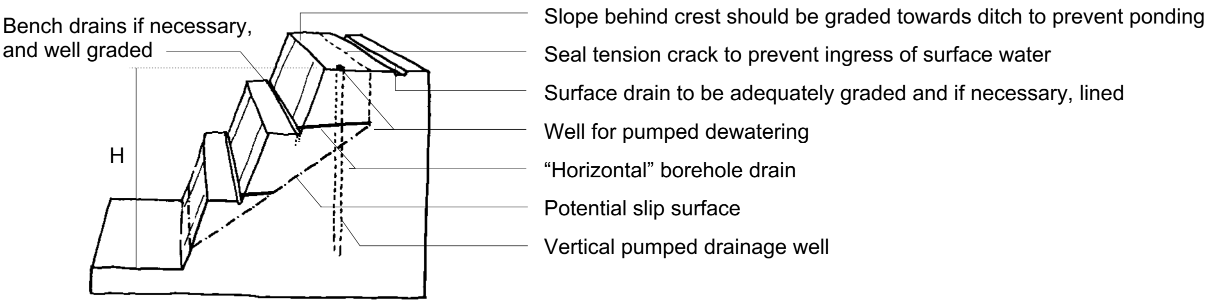


Fig. 5.17 Idealised slope drainage measures

essential to have more detailed geotechnical assessment as defined in Regulation 33 and Schedule 1 of the Quarries Regulations. This has to be undertaken by a geotechnical specialist (as defined in Regulation 2), if such a specialist considers the hazard is indeed significant.

- Daily inspections of all working places as required by the Quarries Regulations (Regulation 12) are an essential part of ensuring adequately safe long-term slopes and timely modifications to slope design. It is usual for all excavated slopes to be inspected (using the Appendix 3 checklist in the Quarries Regulations) once a week.

- Final slope stability needs to consider safety during operation/construction and in respect of quarry after-use and the access required.

- A risk-based approach to final slopes is appropriate to ensure matched and commensurate safety measures are in place.

- Final slopes should be carefully set out and based on a design that is geotechnically well founded. It may be a generic design rather than a specific design, but the latter may be required if adverse structural or groundwater conditions are present or if weak soil/rock strengths exist within an intended slope.

- Final slopes should always be based on experience with parallel situations and materials having regard to the strength, structure of the rocks/soils and to the groundwater conditions.

- Neither Mineral Planning Authorities nor the HSE can or should provide quarry operators with any secure slope design. Quarry operators must obtain proper professional geotechnical advice to confirm the adequacy of any landscape treatment requirements.

- Face heights of benches should always be 15m or less.

- Face profiles, in plan, should avoid noses/corners since these can give rise to dangerous rockfall and cracking.

- Face profiles, in section, with small steps usually appear to be more natural and can benefit stability/access.

- Persistent inclined bedding/jointing can give rise to problems, and are commonly the source of large slope failures.

- Identical slopes are rarely suitable for all faces in a single rock quarry.

- Benching should always be used to protect those working at lower levels (even on final faces).

- Benches should only be removed from the bottom upwards, and then only if there will be no final access to lower levels and the overall slope remains safe.

- Working benches/levels require edge protection at all times for (a) rockfall protection from above (b) falls onto lower levels (Regulation 13). Edge protection itself must be secure.

- The upper benches are generally the most weathered and the loci of most slope failures and rockfall.

- Final slopes in soils (clays, sands, silts) should not exceed 2 to 3m in height with adequate benching if public access is required, *e.g.* to SSSIs. For SSSIs with rock faces, bench heights should not exceed 5m and be of adequate width if safe access is required.

- The placing of materials on benches for landscaping needs to be assessed in geotechnical terms, *e.g.* slope loading, drainage and rockfall prevention.

- Excavated slopes should always incorporate adequate measures to protect against groundwater seepages and surface water run-off likely to damage or destabilise the slope.

- Drainage of benches should be along not across benches. If drainage has to cross a bench crest suitable protection/piping should be provided.

- Drainage is an important issue when

erosion may be marked, *e.g.* sands and clays.

- Drainage on benches and at the crest of a slope should be low maintenance and ideally self-cleaning.
- A rockhead bench of at least 3m should be provided at the base of all thick superficial deposits (thicker than 5m).
- Overall quarry slopes that are steeper than 1in 1 (45°) in rock will rarely allow for significant on-bench restoration.
- Overall quarry slopes that are steeper than 1 in 0.5 (62°) in rock will not usually provide adequate rockfall protection.
- Whilst in general, flatter slopes are more stable than steeper slopes, there are situations when sub-horizontal weak clay bands/shear zones are present, where the reverse is true.
- Final slopes in sands should not be steeper than 1 in 1.5 or preferably 1 in 2. Such slopes might not be stable if saturated, underlain by clay or including clays or clay bands at or above the toe of the slope.
- Final slopes that incorporate bands of erodible materials should be protected by granular, free draining material.
- Final faces should be scaled to remove loose rock and reduce the risks to those involved in the final steps of quarrying as well as restoration/planting *etc*.
- Excavated faces are frequently cleanest when excavated with a backhoe rather than a loading shovel and with a breaker rather than blasting.
- Final slopes that seek to replicate or simulate natural slopes should be safe, relate to the materials being copied and be based on appropriate measured face angles.
- Rockfall is important; it is best prevented or dealt with at the time of excavation or while access remains viable.
- Pre-split blasting may help to minimise or avoid loose rock on a face, however this method of producing a final face does not prevent sliding out or collapses if adverse structures are present in the rock.
- Vertical blast holes frequently cause break back and rockfall from the top 2 to 3m of a bench face with inclined jointing.
- Where rockfall or larger falls of ground are possible from a final quarry face fencing or barriers at the toe and crest of the slope should be provided a sufficient distance away from the face to control the risk of accidents.
- Larger slope failures are not common in quarries but where they occur they can have a significant visual and well as psychological effect on the local community. The potential for large scale bedding plane failures should always be considered in inclined strata.
- Mineral Planning Authorities should not prevent the establishment of secure slopes or adequate rockfall protection measures if there is a risk that the public might access the site.
- Fill materials can be used to buttress an unstable final face, but the extent of buttressing and its effect on drainage and stability at lower levels should also be considered. MPAs should check that sufficient waste materials will arise during working for any proposed buttressing or restoration works.
- It is most unwise to work to the limits of a site ownership with no standoff to the site boundary unless very detailed analyses of the long-term stability have been undertaken.
- Access is a paramount need if there is any likely requirement for remedial work to the quarry faces or to planting *etc*.
- If long term access to a rock/soil face is essential, say for an SSSI, then health and safety becomes critical. Either access must be restricted, controlled/regulated according to current site conditions or faces protected by netting or the like or made quite safe by excavation. They should be regularly appraised (see

Appendix 2).

- The crest of high faces above a quarry excavation should always be fenced and marked with appropriate signs in a suitable manner so as to prevent accidental access.

- Before the closure of a quarry a hazard appraisal should be completed in the context of intended or likely future uses (see Appendix 2).

- A biannual re-appraisal of the hazards associated with completed quarry faces should be undertaken for the first 6 years following completion of quarrying *etc*. to confirm the adequacy of slopes as left.

- Mineral leases should incorporate clauses requiring the rectification of stability problems for a period of up to 7 years by requiring operating companies to enter into insurance bonds *etc.* to cover the cost of remedial works.

- Planting and plant cover should not be provided if (a) the planting *etc*. will obscure features of scientific importance (SSSIs and RIGs) (b) it would damage bench/face drainage, (c) it would adversely affect stability or induce rockfall.

Introduction

This Section examines specific restoration techniques and illustrates them with good and bad examples of landscape restoration and slope stability; they are grouped under the four main headings of:

- Rim/Crests.
- Face.
- Bench.
- Floor.

Rims/Crests

General geotechnical issues for works to be undertaken at the rim must consider:

- Preparation of suitable risk assessments and excavation and tipping rules.
- The crest of high faces above a quarry excavation should always be fenced with appropriate signs in a suitable manner so as to prevent accidental access.
- Access is a paramount need if there is any likely requirement for remedial work to the quarry faces or to planting *etc.*
- It is most unwise to work to the limits of a site ownership with no standoff to the site boundary unless very detailed analyses of the long-term stability have been undertaken.
- Superficial deposits are mostly weaker than the underlying mineral and must be considered separately in respect of stability. The upper benches are generally the most weathered and often the loci of many slope failures and rockfall.
- Slope drainage at the rim/crest of the slope is important particularly when the effects of erosion may be marked *e.g.* in sands and clays. Drainage at the crest and on benches of a slope should be low maintenance and ideally self-cleaning.

Rim Technique No. 1 - Roll Over

Roll over is the landscape technique whereby the surrounding landform, land use and vegetation is continued into the quarry by tipping and/or shaping the rim. It is most easily achieved using the *in-situ* overburden/soil on the rim but can be effected by the tipping of materials provided these can be placed in a secure fashion. It is important that the slopes created follow and reflect the adjoining landform in terms of convexity or concavity. Roll over as a method benefits from early planning/construction such that access and adequate land at the rim has been allocated.

The effects of reprofiling and crest loading on slope stability must be considered *viz*:

- The presence, thickness and components of any superficial materials with respect to achievable slope angles.
- Reprofiling alters the loading distribution in the slope. Whilst the flattening of a slope is generally beneficial with respect to stability there are certain situations where the reverse is true (*e.g.* where sub-horizontal weak units are present). The placement of fill at the crest of a slope, and the removal of materials from the toe of a slope may promote instability (this is especially applicable where the potential for circular instability exists).
- Where drainage exists prior to reprofiling, then care must be taken to properly accommodate such measures into any new system. Failure to do so may result in blockages and a build up of water pressures in the slope resulting in instability and/or erosion.

Fig. 6.1 Successful roll over on quarry rim

Rim Technique No. 2 - Nibbling

Whereas roll over is created in weaker materials above the upper face, the top of the upper face itself may be shaped to give a more varied, less rectilinear profile. Again, early planning/construction allows for ease of access and adequate land at the rim. It is important that the landscape in the surrounding area is studied so that the proportions and shapes of rock outcrops (sometimes known as buttresses) are reflected by this technique. In general, randomness and a lack of repetition is desirable. Maximum effort should be placed on those sections of the rim which are the most visible from outside the quarry.

The consequence of these activities is the generation of noses and indents into the slope. The production of such features often gives rise to localised face instability, the magnitude of which depends on construction method (see Chapters 4 and 5). Such features should be dressed using a backhoe or breaker to remove any loose material.

Fig. 6.2 Buttresses inserted into a roll over crest

Rim Technique No. 3 - Bunds and Mounds

Bunds and mounds on the rim of a quarry may be necessary from an early stage to provide visual/noise screening. Wherever possible they should be designed such that they integrate with the existing surrounding landscape and they avoid rectilinear or obviously man-made shapes.

To avoid destroying such features towards the end of quarrying and any maturing associated planting, they should be designed for final integration, for example with roll over or nibbling (see Figs. 6.1 and 6.2). Larger mounds may be able to incorporate local outcrop features such as tors or crags and contribute to the breaking up of any flat or rectilinear rim (see Fig. 6.3).

The consequences of crest loading on the slope must be considered as previously in respect of stability and drainage as outlined in the roll over technique above. The stability may be compromised if undercut from below; an adequate stand-off from the crest of the slope is required. Examples of where undercutting has lead to induced instability are given in Chapter 5.

Fig. 6.3 Natural rock outcrops on a skyline

Fig. 6.4 Artificial shapes on a skyline should be avoided

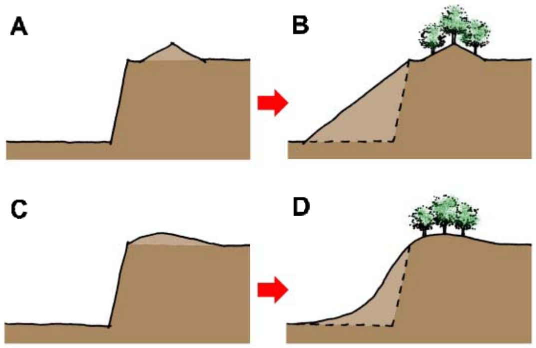


Fig. 6.5 It is easier to integrate 'Natural-shaped' peripheral bunds into restored slopes (*cf.* B and D)

Fig. 6.6 Beneficial effects of visually breaking up a crest line with vegetation

Rim Technique No. 4 - Planting

All planting should be installed at the earliest opportunity; this maximises growth time, minimises the need for large stock and reduces the cost. Planting should always comprise species which grow in the local area and in similar microclimatic conditions. The importance of on-going maintenance and replacement should not be underestimated. The ten main causes of planting failure are drought, drowning, wind, frost, damage by animals, damage from humans, lack of nutrients, smothering, disease and unseasonal planting. All of these can be minimised by using the right species, at the right size with proper staking, tubing and spats. Soils need to be fertile and to have structure; they should be of adequate thickness to avoid drought. Where waterlogging is inevitable, a drainage scheme may be necessary. Planted areas benefit from stock/human proof fencing which delineate them. There is no substitute for regular inspection, maintenance and replacement. Wherever possible, existing planting should be integrated and linked into the restoration scheme using new planting.

Repetitive planting shapes or species groups should be avoided (see Fig. 6.8).

Planting and plant cover should not be provided if the planting etc. will obscure features of scientific importance (SSSIs and RIGs) or it would damage any drainage measures or adversely affect stability or induce rockfall. Where large trees exist or grow on the top of the upper face, they should be removed if their roots begin to break up the *in-situ* rock and promote further instability.

Fig. 6.7 Poor growth in exposed hillside quarry

Fig. 6.8 Repetitive planting in groups

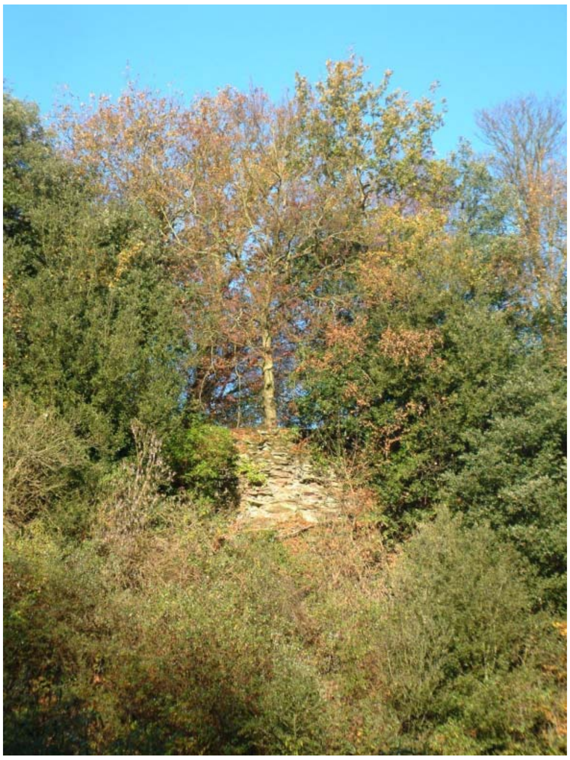


Fig. 6.9 Large tree on a quarry rim

Rim Technique No. 5 - Avoidance of negative features

The rim is likely to be one of the most visible parts of a quarry or restoration scheme; it is also often the skyline from many viewpoints. Any man-made features or unattractive landform/vegetation will be both exaggerated and highlighted in silhouette.

Fig. 6 .10 Old quarry plant on a rim

The commonest elements which are left on the rim include old plant, machinery and buildings, soil retaining structures such as gabions see Fig 6.11 and edge protection blocks which can give a castellated skyline (see Fig. 6.13).

Fig. 6.11 Man-made support buttressing with gabions

Similarly, linear or regular features such as hedges and fences and block planting can emphasise the rectilinear or man-made shape of the quarry rim.

Fig. 6.12 Trimmed hedge emphasises quarry skyline

Where access or conveyor routes have created notches these, too, should be re-examined to see whether they cannot be improved by, for example, creating interlocking spurs to prevent direct views through any notch (see Fig. 6.14).

Fig. 6.13 Roadside edge protection boulders on rim

Fig. 6.14 Views into this quarry could be reduced by interlocking spurs

Rim Technique No. 6 - Retention of features

In contrast to the removal of negative elements, some features on the skyline/rim warrant retention and enhancement. Existing woodland may be integrated with early and final restoration planting to soften skylines and provide attractive silhouettes.

Fig. 6.16 Irregular tree line breaks up a linear slope crest

Similarly, aesthetically pleasing and interesting industrial archaeology and heritage items can be retained providing a link to the quarrying past. Such positive uses may encourage public access which raises issues of safety.

Fig. 6.17 Old mining chimney is an acceptable feature in the landscape

Fig. 6.15 Natural woodland at crest of slope on LHS copied in bench tree planting on RHS

Rim Technique No. 7 - Variation in rim

In keeping with earlier techniques, there should be an overall objective within the constraints of quarrying, safety and land ownership to create a variable rim in all the dimensions. The overriding objective should be to avoid rectilinear and repetitive forms. While long term slope stability and public safety take precedence, large bluffs and variable upper face heights are a dramatic way to break up the skyline.

Features that comprise a nose or corner often give rise to continued instability and rockfall. The long term security of such features must be considered in detail. Where instability may be a problem then health and safety and the elimination of the hazard should be the priority.

Fig. 6.18 Prominent nose as a dramatic feature

Fig. 6.19 A nose of regular form extending into a final quarry face

Rim Technique No. 8 - Remedial work

Where there are failures/instability or potential for these, there is no alternative but to undertake remedial work. If there is adequate land ownership behind the rim, the problems are reduced and the options are wider.

Remedial measures should, where possible, improve and establish permanent access and be designed to minimise future maintenance. The long term stability of slopes in both superficial materials and rock needs to be considered as well as appropriate drainage systems. Where significant thicknesses of superficials are present and room is available, then an appropriately sized rockhead bench and edge protection should be installed. Slope stabilisation techniques have been outlined in Chapter 5 but are very expensive for large slopes.

Where access to, or space for, planting is not available, re-configured faces or slopes may be hydroseeded to introduce some vegetative cover.

Fig. 6.20 Soil nailing as part of a stabilisation project shown in Fig. 6.21

Fig. 6.21 Stabilisation of superficial materials above a steep rock slope to protect land behind the quarry limits

Fig. 6.22 Tree planting to protect against soil erosion on restored slopes in a sand pit

Faces

General geotechnical issues for slope design and works to be undertaken on faces must consider:

- Preparation of suitable risk assessments and excavation and tipping rules before excavation, remedial works or landscaping commences.
- Excavated faces are frequently cleanest when excavated with a backhoe rather than a loading shovel and with a breaker rather than blasting.
- Face heights of benches should always be kept at 15m or less.
- Final slopes in sands should not be steeper than 1 in 1.5 or preferably 1 in 2. Such slopes might not be stable if saturated or underlain by clay if they include clays or clay bands at or above the toe of the slope.
- Final slopes in soils (clays, sands, silts) should not exceed 2 to 3m in height with adequate benching if public access is required e.g. to SSSIs. For SSSIs with rock faces bench heights should not exceed 5m and be of adequate width if safe access is required.
- Face profiles, in plan, should avoid noses/corners since these can give rise to dangerous rockfalls and cracking.
- Face profiles, in section, with small steps can benefit stability and access.
- Identical slopes are rarely suitable for all faces in a single rock quarry.
- Vertical blast holes frequently cause break back with out-of-vertical jointing causing rockfall from the upper section of a bench face. Stemming may also result in localised overhangs of loosened rock at the crest even with inclined blast holes.
- Excavated slopes should always incorporate adequate measures to protect against groundwater seepages and surface water run-off likely to damage or destabilise the slope.

Face Technique No.1 - Scaling of faces

Rockfall constitutes the most frequent cause of accidents in working quarries. It remains a significant hazard in final quarry slopes particularly when access to faces continues (to SSSIs *etc*). Final faces should be scaled to remove loose rock and reduce the risks to those involved in the final steps of quarrying as well as restoration/planting etc.

Scaling of faces should only be attempted if it is safe to do so and following specific hazard and risk assessment. Scaling may be undertaken either from above or below by machine where adequate bench widths and edge protection exists. Scaling is often achieved using a backhoe sitting on the blast pile which dresses the face as the blast pile is reduced. In more sensitive or inaccessible locations removal using specialist abseil contractors is possible but expensive. Rockfall is best prevented or dealt with at the time of excavation or while access remains viable.

The method of final face excavation dictates the amount of potential scaling and ongoing maintenance required. The cleanest faces can be produced by pre-split blasting but this has visual impact implications (see Fig. 6.35). Excavation of final faces using face shovels should be avoided as this often results in a further loosening of the strata. Scaling should be undertaken before any planting or hydroseeding is attempted.

Table 6.1

Machine scaling of faces: some basic rules

Equipment

- Use the longest reach crawler mounted backhoe available. *Do not use a front end loader or face shovel for scaling.*
- A rock bucket is suitable for dislodging loose rock but a wedge or tooth attachment may be preferred.
- Always work as far from the crest or toe as practicable.
- Machines must be fitted with protection against roll over (ROPS) and falling objects (FOPS).
- Generally work with the crawler tracks parallel to the crest or toe of the slope.

Precautions

- Check the extent of overhangs in the face to be scaled *before working*.
- Confirm the location of tension cracks behind the crest including breakback *before working*.
- Check the location of previously fallen rock *before working*.
- Inspect faces for rockfall from the side as well as in front to see where open joints and cracks are present. *Do not approach a face where the rock may fall*.
- Consider the area where scaled rock may fall.
- Identify a danger zone to be established and from which personnel are excluded *before working*.
- Only work in conditions of good visibility.

Scaling from crest

- This is the *preferred method for scaling*.
- *Do not cross tension cracks* with the crawler tracks.
- Always work with a scaling assistant at the crest who is equipped to avoid falls *e.g.* with a secured harness.
- The machine driver must be in direct communication with the scaling assistant.
- The scaling assistant is responsible for ensuring the danger zone is clear.
- Remove loose rock by levering cracks outwards from above rather than from below.
- Work from the side and not behind large buttresses or pillars of loose rock.
- *Do not approach too close to the edge*; if a rock cannot be removed *leave it*.

Scaling from below

- The major risk is falling rock; it does not always fall or bounce perpendicular to the face.
- *Do not work directly in front of the rock being removed* especially when removing a loose pillar or buttress. Ideally, in plan, the boom should be at 45° to the quarry face.
- Scale the face downwards in sequence, pushing material away from, rather than towards, the machine.
- The boom of the backhoe *should not be raised significantly above 45°* from the horizontal since this may severely reduce the distance between the face and the machine.
- It is always safer to scale lower rather than higher slopes. It is usually safer to scale from the blast pile than from the quarry floor.
- Before working *form a rock trap* using loose material or form a hollow in the blast pile at the toe of the face if the machine is standing above the quarry floor.

Face Technique No. 2 - Variation

In general, it is the upper faces which are the most visible from outside the quarry; any variation in height or angle will, therefore, reduce the visual impact. While lower faces/benches tend to be parallel and rectilinear, the upper face may have variation in height as it accommodates the undulating or sloping nature of the existing ground surface. Within the strict confines of efficient and safe excavation, variety which simulates the natural surroundings could be of value. The upper faces are also often seen in silhouette and usually receive the most sunlight. Scope exists, therefore, to introduce natural randomness, changes in direction, large stable bluffs *etc.* in order to emphasise shadow and disguise the regular nature of faces.

Where explosives are used to form headwall features (as in restoration blasting) the resulting rock faces are generally unsatisfactorily loose and unstable giving rise to toppling failures and rockfall. Many of the buttresses found in the past are too small and too regular in their positioning.

Interesting, variable and stable rock features may be produced by blasting and followed by dressing and scaling by an excavator. Two different techniques are used. Shallow final faces may be produced from the final production blast comprising a series of variable length holes to produce a 1 in 1 final rock face (see Fig. 6.23). Alternatively, the rounding of the crest may be achieved by pneumatic breakers from above of the upper few metres of a face which often form the source of much rockfall.

Fig. 6.23 Interesting low angle final face produced by stepped blasting

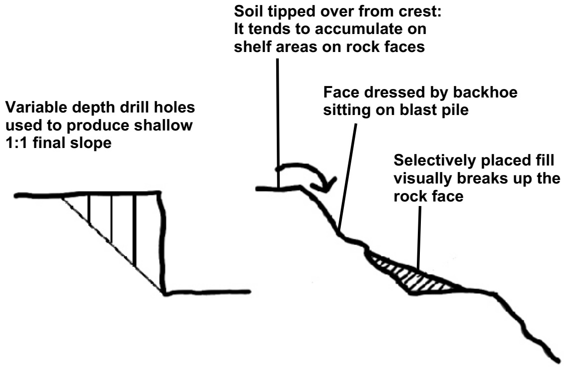


Fig. 6.24 Methods of final face treatment used to form face in Fig. 6.23

Fig. 6.25 A buttress feature in a final slope

Face Technique No. 3 - Tipping against the face

The commonest technique for disguising or hiding faces is to tip material against them. However if such tipped material is placed at constant heights and angles it may emphasise the regularity and man-made nature of the faces and benches if these are not present in natural slopes in the vicinity.

Tipping against the face may help with stability by (a) buttressing the entire slope or (b) covering weaker bands within the face which may weather at different rates and cause localised undercutting and instability. Care should be taken to avoid the blocking of drainage measures installed to assist in the original slope stability.

Even small variations in height and angle (and concavity/convexity) may increase the visual effects of sunlight and shadow. Variations in planting and grassing further break up any regularity and rhythm. If there is obvious folding, dipping or sinuous bedding in a face, the eye is drawn to any tipping which cuts across such elements in a straight line; tipping against faces should, where possible, follow the naturally occurring lines in the face. Tipping can in controlled circumstances give access to the upper parts of faces which may be of geological or other interest.

Face Technique No. 4 - Soiling, grassing and hydroseeding

Establishing any form of plant growth on faces is difficult and, in many cases, undesirable where it may encourage rockfall and degradation or obscure features in an SSSI. However, the two commonest methods include tipping soils from the bench above such that it collects in crevices and hydroseeding the faces to introduce plants, growing medium and an 'adhesive' which initially helps the root growth to establish. Any pockets of plant growth on faces are subject to the maximum range of microclimatic and hydrological extremes, it is, therefore, critical that only the hardiest species from the local flora are considered.

Fig. 6.26 Tipping from floor to rim over a blasted bench system

Fig. 6.27 Full height slope buttressing

Fig. 6.28 Irregular, partial buttressing of a final face

Fig. 6.29 Rock feature protruding from a long backfill buttress; the feature being a rounded bench crest of Fig. 4.6

Fig. 6.30 Floor raising by backfill to support the lower section of a final slope

Fig. 6.31 Localised plant growth from soiling a steep face

Face Technique No. 5 - Planting against faces

Planting against faces (especially on tipped material) has two major contributions to quarry restoration. Firstly, as it grows it screens the face, reducing the proportion of rock visible and introducing softening, colour, seasonal change and ecological value. Secondly, blocks of planting can help in the containment or reduction in rockfall by trapping material. Thick planting may also be a method by which the public are discouraged from approaching certain faces or benches. All of the factors which cause planting to fail listed in Rim Technique No.4 apply here.

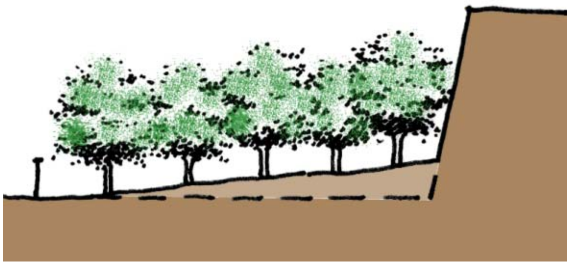


Fig. 6.32 Fenced and planted area at base of face

Fig. 6.33 Fencing and tree planting near a rock face subject to rock fall

Face Technique No. 6 - Colour

Colour as a factor within a restoration scheme may not be the most important but it is often ignored completely. There are techniques by which the ageing process (including the growth of lichens, moulds and mosses) is encouraged by the application (spraying) of nutrient-rich liquids and fertilisers. On rock faces as distinct as the Devonian red limestones, for example, the contrast between a fresh red exposure and the dark, almost black, older faces is dramatic.

Fig. 6.34 Variable colours in a rock face relating to age of exposure

The upper faces should be designed so that they do not degrade and slip creating bright new scars. Colour can also be introduced into a quarry restoration scheme by appropriate tree/shrub planting which through the seasons offers visual distraction from the faces.

Face Technique No. 7- Blast markings

Whichever blasting or excavation methods are used through the life of the quarry, special attention needs to be given to reduce blast markings on the final face. Traces of drilling and, in particular, the close repetition of pre-split blast holes should be avoided where visual impacts would be inappropriate. The eye is invariably drawn to the regularity of vertical stripes across the variable geology of a face.

Although pre-split blasting has some benefits in reducing or avoiding loose rock on a face, it should be restricted to locations where access could be seriously affected by rockfall (*e.g.* major haul roads) and cannot be handled by other means (*e.g.* scaling). It should be recognised that this method of producing a final face does not prevent sliding out or collapses if adverse structures are present in the rock.

Fig. 6.35 Pre-split blast holes in a final rock face (Note upper edge protection is not secure)

Face Technique No. 8 - Netting/Matting

The netting of faces with galvanised wire mesh has the advantage in restoration terms of containing spalling and rockfall, but it does not prevent all rockfall. It may provide more scope for vegetative growth but it should not be used in this way. However, netting is (a) expensive and should be used only in critical areas, (b) has maintenance requirements and needs regular cleaning out if significant volumes of material accumulate behind it and (c) has a finite life.

Matting on gentler tipped or graded slopes helps in stabilising such slopes and minimising erosion while the grass or trees/shrubs establish their root systems which themselves contribute to the soil stabilisation. In geotechnical terms matting as a technique can limit surface water inflow and reduce erosion but requires a good understanding of the spacing and depth of pegging required to avoid triggering a large scale surface slide. Matting should always allow for seepage of groundwater and never act as a low permeability membrane.

Fig. 6.36 Matting pegged to a rubble slope to protect lower slopes from rockfall

Face Technique No. 9 - Encouraging Fauna

One consequence of forming rock faces is that they may be a rare habitat in certain landscapes and locations. This, coupled with the specific microclimates of quarries offers the opportunity to provide sites for rare or important flora and fauna. Bio-diversity may be enhanced. Perhaps, the best example of this comes from the profusion of peregrine falcons nesting high in restored (and active) hard rock quarries. They can be encouraged by the provision of ledges (1.0m wide by 0.5 to 1.0m in depth), partially overhung, between 5 and 15 metres below the top of the upper faces. Any attempt to form such inaccessible faces, that may be subject to rockfall, should be consistent with intended quarry after-use and landscape objectives.

Face Technique No. 10 - Preservation of Important Geology

Another consequence of quarrying is the exposure of SSSIs. Two aspects of sustainability have to be addressed *i.e.* the security of visitors and the continued exposure of the critical features. Planting and plant cover should not be provided if it will obscure features of scientific importance.

In order to preserve the SSSI the exact location and nature of the feature must be established. Often the entire quarry may be designated a SSSI when only one area of a single face may be significant. Once the location of the SSSI is known then access may be planned (and fenced) and the adjacent faces secured appropriately. Where the full geological sequence comprises the feature of interest, then placement of fill against the faces may facilitate access to the complete sequence. Conversely, a sequence of inclined strata is best viewed along horizontal benches. Low final faces of less than 5m in rock and 2m in soils are desirable.

Benches

General geotechnical issues for works to be undertaken at or on benches must consider:

- Preparation of suitable risk assessments and excavation and tipping rules.
- Benching should be used at the very least to protect those working at lower levels (even on final faces).
- A rockhead bench of at least 3m should be provided at the base of all thick superficial deposits (thicker than 5m).
- Overall quarry slopes that are steeper than 1 in 1 (45°) in rock will rarely allow for significant on-bench restoration.
- Working benches/levels require edge protection at all times for (a) rockfall from above (b) falls onto lower levels.
- Overall quarry slopes that are steeper than 1 in 0.5 (62°) in rock will not usually provide adequate rockfall protection.
- Drainage of benches should be along not across benches. If drainage has to cross a bench crest suitable protection/piping should be provided.
- The placing of materials on benches for landscaping needs to be assessed in geotechnical terms with respect to slope loading and implications for rockfall.
- Benches should only be removed from the bottom upwards and then only if there will be no final access to lower levels, the final face will not be seen from outside the quarry and the overall slope remains safe.

Bench Technique No. 1 - Removal by tipping

Waste materials and soils may be tipped to bury completely both the bench and face; this may be extended to hide all the benches/faces and to allow the contiguous landscape to flow down from the rim to the floor. Where there is inadequate material to bury every bench, a fundamental decision has to be made - whether to tip partially on many benches or to concentrate the material along one length of quarry where the benches/faces are wholly buried. Circumstances will vary but it is usually preferable to concentrate materials in one area; this tends to destroy the “hole” like character of a quarry to improve visual ‘interest’ and to increase the access/after-use options.

Fig. 6.37 Benching of a sand excavation

Fig. 6.38 **Benching obscured by restoration tipping (*cf* Fig. 6.37)**

The consequences of crest loading on the stability of the underlying slope and the consequences of blocking face drainage measures on the tipped materials must be considered. MPAs should check that sufficient waste materials will arise during working for any buttressing or restoration works required for the final restoration proposals.

Tipping against the entire slope may also aid in the stability of the both individual faces or the entire slope (where bench widths are sufficient). Buttressing of inclined strata containing interbedded weak bands is an occasionally used method of securing faces. In such situations it is vital that a detailed knowledge of the structure and material shear strengths are known and that the excavation sequences are undertaken in short bays and immediately followed by buttressing. Specialist geotechnical advice should be used in such situations. Similarly the complete burial of benches and faces should never be undertaken purely by end tipping. The structure and placement of such volumes of spoil needs careful design. Experience shows that in such sites angle of repose tipping almost always is prone to extension gulleying and does not adequately revegetate.

Bench Technique No. 2 - Partial removal by tipping

There are two main configurations for the partial tipping of a bench. As can be seen in the accompanying figure, material may be tipped sloping back to the face or away from the face.

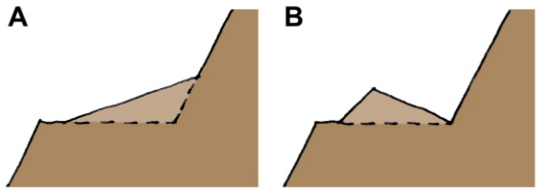


Fig. 6.39 Bench tipping angled away from the face (A) and back to the face (B)

Similar crest loading and drainage measures to those discussed above must be taken into account.

Where the volume of fill materials available precludes the complete tipping against a face, then partial tipping against the face will result in some buttressing. The effects of rockfall can be reduced by limiting the area and height from which rockfall may occur. Rockfall containment bunds can be placed to form the crest of the buttressing materials subsequently deposited on the bench (see Fig. 4.5).

Fig. 6.40 Successful tipping against face

Fig. 6.41 Partial tipping against face (incorporating a rockfall protection bund in front of the rock face)

Backfill placed sloping away from the face may look natural but in the absence of edge protection projects falling material further out from the toe and increases run-off, erosion and evaporation. Spoil placed sloping toward the toe of the bench has the benefit of aiding the containment of rockfall and retaining moisture for plant growth.

Fig. 6.42 Tip above a final slope with no rock head bench and lower bench filled with forward sloping waste

Bench Technique No. 3 - Avoiding repetition

As with rims and faces, repetition, rectilinear lines, parallel lines and man-made shapes all emphasise the visual impact of a quarry. Within the constraints of quarrying efficiency and safety, any variation in bench width, height and angles helps to reduce the visual impact.

Similarly, the retention of ramps achieves the same effect while offering access. Where benches are in parallel, rectilinear groups, the visual impact can be reduced by localised partial tipping and non-linear planting. It should however be appreciated that where access or a bench remains there should always be at least bunding 1.5 metres high along the crest of that bench.

Fig. 6.43 Localised softening of repetitive benching with limited plant growth

Bench Technique No. 4 - Planting and vegetation

It is generally easier to fence off and exclude humans and animals from planted areas on benches. Against this advantage, is the fact that bench planting may have to suffer extremes of temperature and water availability. Fertility may diminish over time as nutrients are washed out. Whichever method of planting is used (hydroseeding, notch or pit planting) the inclusion of fertiliser and water-retaining products is essential. Adequate safe access must be retained so that on-going maintenance can be undertaken. Whilst natural revegetation is to be encouraged, not all species are helpful to long-term restoration objectives. Buddleia and certain aggressive grasses can swamp and shade out the more valuable trees and shrubs. Again regular on-going inspection and maintenance is important.

Fig. 6.44 Successful bench planting

Fig. 6.45 Natural revegetation on benches

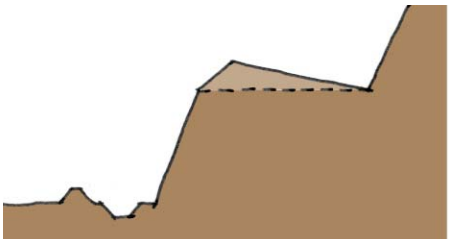


Fig. 6.46 Rockfall bounce absorbed by fill

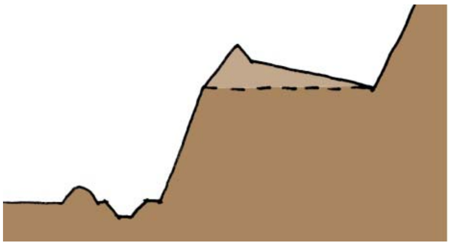


Fig. 6.47 Rockfall containment by ditch and by bund

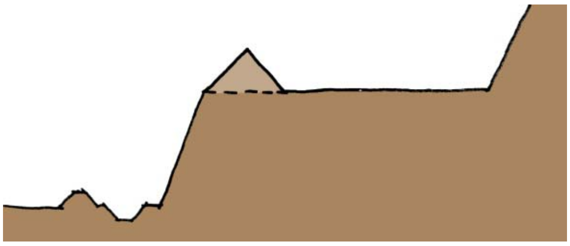


Fig. 6.48 Rockfall containment by bench width and suitable edge protection

Bench Technique No. 5 - Rockfall containment

Details on the methods of rockfall prevention and containment are set out in Chapter 5. Where slopes are steeper than 1 in 0.5 (62°) in rock and rockfall is likely adequate rockfall protection should be provided. Passive containment measures which may be installed on benches and at the toe of a face include:

- Placement of fill on benches to absorb the impact of falling rock. (see Fig. 6.46)
- Containment ditches or bunds at both the toe of a face and/or edge protection of sufficient height. (see Fig. 6. 47)
- Benches of sufficient width with edge protection if access is required to allow for scaling and removal of accumulated materials. (see Fig. 6.48)

Where rockfall or larger falls of ground are possible from a final quarry face fencing and containment bunding at the toe of the slope should be provided a sufficient distance away from the face to control the risk of accidents. Mineral Planning Authorities should not prevent the establishment of secure slopes or adequate rockfall protection measures if there is a risk that the public might access the site.

Bench Technique No. 6 - Maintaining access

The maintenance of access is important for undertaking any remedial works to faces and planting. This includes adequate access to the crest as well as the provision of intermediate benches to protect persons and plant below. Insufficient stand-off from ownership boundaries and subsequent slope failure or progressive failure may result in a loss of support into third party land. Planting is still possible on edge protection if benches are required for access.

Fig. 6.49 High bench faces with no on-bench access and active rockfall

Fig. 6.50 Bench planting with no access for future maintenance

Floor

When considering restoration working at the toe or on the floor of a quarry the following should be considered:

- Preparation of suitable risk assessments and excavation and tipping rules.
- Rockfall can travel many metres from the toe of a high slope in certain settings .
- Requirements for rockfall traps and bunds.
- An understanding of the levels to which groundwater (or surface water) may rise after quarrying ceases.
- An understanding of drainage requirements on the floor of the quarry.
- If the floor of a quarry comprises a footwall or inclined bedding plane, the security of that sloping floor must be established.

Floor Technique No. 1 - Fill placement

Tipping on the quarry floor increases the afteruse options (agriculture, forestry, recreation and nature conservation). It can also be integrated in any tipping at the base of the quarry walls or on benches. Quarry floors are often badly drained and a comprehensive drainage scheme may be necessary to maximise afteruse options and plant growth. Fill placement at the base of the lowest face may be configured to aid in rockfall containment. Variable slope gradients in placed fill give a more interesting final land form.

Development on a quarry floor by way of after-use may require controlled and uniform compaction of the fill materials and the avoidance of steps in the floor of the quarry. Such precautions should aim to reduce or eliminate the risk of damaging differential settlements to structures built subsequently.

Fig. 6.51 Undulating backfill on quarry floor

Fig. 6. 52 Undulating backfill on sand pit floor

Floor Technique No. 2 - Planting

In addition to aspects of planting already discussed, it is generally of value to concentrate tree and shrub planting at the base of the quarry walls. This provides three functions, rockfall containment, keeping the public away from the faces (in conjunction with fencing where required) and the screening of the lower faces. It also maximises the after-use possibilities for the central quarry floor. Microclimatic factors, especially shadow and frost, are important for planting on the floor of quarries.

It is usual to avoid public access to the edge of water bodies in restored quarries unless benches are provided that restrict sudden access into deeper water. Jumping and diving from rock faces into water is a quite hazardous activity but one that is well known in some closed (and even active) quarries. It should be noted that in hot years many more people drown in flooded quarries than are killed working in them.

Fig. 6.53 Tree planting groups on sloping quarry floor

Floor Technique No. 3 - Water

Water in the floor of quarries, while a danger in its own right, can be used like planting to keep the public away from dangerous quarry faces and slopes. Users of water for sailing *etc*. should be aware of rockfall risks. Water also provides further variety of afteruse. It also performs other functions such as a softening visually of the quarry or a magnification of certain heights or features by reflection.

Fig. 6.55 Deep flooded quarry workings

Fig. 6.54 Water preventing access to the toe of steep rock faces

Fig. 6.56 Lake and shallows incorporated into floor restoration

Floor Technique 4 - Planar/footwall slopes

Large inclined quarry floors sometimes result from working to single bedding surfaces . This can at times be the source of large slope failures. Slab failures may occur where the pavement is undercut either by excavation or faulting; the presence of interbedded weak materials is not a prerequisite for failure. Slab failures may also occur on quarry deepening where the weight of the slab causes the toe to buckle or fracture under its own weight; increasing water pressure with depth is also critical to stability.

The development of the sidewalls and low wall in such excavations must also be carefully planned to avoid the undercutting of bedding as the excavation deepens. Similarly, the placement of fill materials on an inclined floor should be arranged to be self buttressing and free draining. Specialist geotechnical advice should be sought in such situations (see Fig. 6.58).

Placement of thin layers of fill and soils parallel to the quarry floor may be problematic if surface water is not managed correctly. Long down slope drainage paths should be avoided by contour drainage.

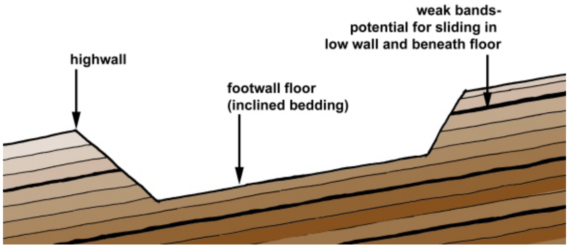


Fig. 6.58 Slab slides on inclined bedding

Fig. 6.57 A quarry with an inclined footwall/floor

Introduction

General and specific landscape restoration techniques have been examined in previous chapters. However, an examination of the results of the quarry visits shows a wide range of usage and success. This chapter describes the most important landscape factors relating to successful restoration of quarry slopes. It also analyses key results and suggests how and why improvements may be made. Table 7.1 shows the summary findings of the landscape survey results.

Key factors

Apart from the application of specific techniques discussed above, there appear to be ten key factors in the production of secure and sustainable slopes with regard to landscape aspects:

- **Pre-planning**

  MPG 7 tells us that,
  "The intended final landform, gradients and drainage of a site should be designed and specified at the outset, with controls in planning conditions as appropriate. For many sites there may need to be some flexibility, and a continuation of the iterative design process, to take account of changes necessitated by operational, geological and mineral working safety demands. However, major planned final landform elements are not easily adjusted when extraction is almost complete, and modifications should not compromise the overall environmental acceptability of the scheme."

  So many of the visited quarries displayed restored final slopes which, while of overall environmental benefit, were the product of *ad hoc*, random or illogical thinking. There was a general unawareness of the value to all (including the quarry operator) of a carefully planned approach albeit with built-in flexibility. So much work had been undertaken because material or machinery/operatives had become available rather than as part of a well-conceived plan.

Fig. 7.1 Successful mixture of landscape restoration techniques

- **Understanding of landscape context**

  For many operators, their quarry has become a separate entity which begins at the boundary fence. All quarry planning, including the creation of secure and sustainable slopes, should begin *inter alia* with an assessment of the surrounding landscape context. Such an assessment should separate out landform (slopes, angles, heights, features *etc.*) from land use (agriculture, forestry, roads, pipelines *etc.*) and from land cover (grass, trees, tarmac, water *etc.*). In addition to a quantitative and qualitative study of the landscape, a visual study should be undertaken to establish who will see what from where.

  Only with the understanding very briefly outlined above can objectives be set for the final slopes.

- **Understanding of the objectives of restoration**

  MPG 7 helps us again by specifying that,
  "Wherever possible and safe to do so the natural gradients and rock features of the surrounding landscape should be imitated when forming new screening banks, soil storage bunds and final faces. Some reclamation schemes may give opportunities to provide new and attractive landscape and landform features."

  Through the landscape context assessment, the quarry operator can discover which landform, landuse and landcover elements should or could be incorporated into the final slopes. The visual impact assessment will have helped to establish which faces or benches are a priority.

Often, the standard minimal bench tipping and planting is wholly inappropriate and a waste of time, money, effort and materials. Certain quarries in coastal or mountainous areas require no more than safe and secure geotechnical solutions to final slopes/faces in order to recreate or integrate with nearby cliff/corrie features. Equally, in undulating grassed landscapes concentrating waste materials along one side of the quarry allows this landscape to sweep down into the grassed floor.

The principal objectives of restoration are threefold: to leave a safe and secure environment, to re-integrate the quarry into the landscape and to provide appropriate after use.

- **Surveys and base data**

It may seem obvious but too many quarries fail to acquire base data on which to plan and design their final restoration. Geotechnical and topographical surveys are fundamental to such planning; these surveys require to be repeated on a regular basis to chart progress, opportunities and potential problems. It is unlikely that all potential quarry restoration objectives established at the outset may be achieved but this is made all the more unlikely if volumes of waste materials, face heights, bench widths, ramp locations *etc.* are not surveyed.

- **Imbalance in use of restoration techniques**

Leading on from the lack of survey and data which leads to inappropriate or wasteful use of materials and opportunity, there appears to be an imbalance in the use of the different restoration techniques.

Fig. 7.2 Successful mixture of planting, natural revegetation and water

Early rim planting or waste tipped on old benches and seeded are techniques which the operator either is obliged to do under the Planning Permissions or is content to do as a means of disposing of a waste accumulation problem. However, the array of potential techniques described in previous chapters can all contribute to a higher quality of safe and sustainable final slopes. These techniques, or combination of techniques, require pre-planning such that they do not conflict and can be applied in a safe, efficient and timely way. This may explain why there is an inappropriate use of techniques because the *optimum moment* for implementation was missed or has passed leaving it as a more expensive, complicated or dangerous enterprise. As an example, rolling over the overburden slope at the top of the rim or nibbling the upper face/rim are best done very early in the quarry development. It is generally safer and cheaper to undertake these techniques at this early stage where access is more straightforward. In addition, any associated planting can be established on finished slopes for the maximum period.

Fig. 7.3 The contrast between fresh and mature slopes

- **Economic awareness**

It is a common misconception that restoration of slopes is always a major cost to the operator. Certainly, the wrong technique or the right technique applied at the wrong time may well be expensive and wasteful. As we have seen, rolling over rim overburden or rim nibbling at a very early stage are cost effective as is the surveying, assessment, planning and design of tipped waste materials. Similarly, the creation of cliff or corrie style faces may be geotechnical solutions requiring no 'soft' landscape restoration. It is very often not the cost of the technique itself but the additional costs of double handling or new ramp creation to provide access or working at height or with more expensive equipment which makes restoration seem expensive.

- **Prioritisation**

Leading on from the previous points it is obvious that a schedule of priorities needs to be established. What maximises safety? What maximises the impact of the restoration? What speeds up the restoration? What is the most efficient way to apply a technique? What is the most cost effective way of achieving restoration? What is the most effective use of materials? Answers to these and a whole series of other questions help the operator prioritise. Such prioritisation and scheduling allows the operator to spread tasks throughout the quarry development. It allows the operator to make informed decisions if some factor changes during quarry development which may affect the restoration techniques open to him.

- **Future flexibility**

There are two distinct aspects to flexibility in the restoration of quarry slopes. Firstly, all the aspects described above including surveying and pre-planning mean that waste materials, ramps, faces, benches *etc*., are in the right place at the right time. Such efficiency in space and time allows for maximum flexibility should circumstances change during quarry development. Secondly, final slopes which most closely reflect those of the surrounding area are the most likely to accommodate any land use which arises in that local area.

- **Public Relations awareness**

  Creating secure, sustainable and appropriate restored slopes at as early a stage as possible is a key way to demonstrate to the local stakeholders the *bona fides* of the operator. Ensuring that rims and upper benches are restored early helps to minimise their impact. Restoration is not a final act of quarrying but a progressive operation. Such rims, faces and benches may be visible for decades before quarrying ceases.

- **Long term vision**

  This point encompasses all the previous points and emphasises the holistic approach. The restoration of slopes is not a minor element in quarry development but one of a whole raft of interconnected elements which need to be planned from the outset and reviewed regularly. Operators and MPAs need to consider the ultimate restored quarry form following any future extensions and not just the restoration under any current Permission. The overall objective has to be maximising the safe and secure long term re-integration of restored quarry slopes into the surrounding landscape in the most efficient and cost effective way.

Fig. 7.4 Excellent integration of a restored quarry into the surrounding landscape

The application of techniques in visited quarries

Over three quarters of the quarries visited used planting on the rim; this was the most commonly used planting technique. This is, perhaps, not surprising given that most quarries need some screening and that rim planting does not impinge on most quarrying activity. It has the advantage of generally being installed at the beginning of a quarry's life. By the time that final slopes/faces are being established, the maturing planting provides a landscape element to continue down into the quarry. The three commonest mistakes encountered were the lack of regular maintenance which minimises the long-term contribution, the inappropriateness of tree/shrub planting in some landscape contexts and the over-use of rim planting such that it emphasises the location and shape of the quarry.

While planting or natural re-vegetation were techniques employed at all quarries visited, it was surprising that only 45% to 55% used either bench or floor planting. The main reason for this, apart from lack of trees in the landscape context, was lack of planning. Bench planting in particular requires the coordination of a number of key factors such as quarrying sequence, bench widths, access, tipping, season *etc.*; it is difficult and undesirable to undertake bench planting on an *ad hoc* basis. However, the advantages of tree/shrub growth particularly on the upper benches are substantial and pre-planning is essential. Planting on the floor at the base of final slopes was also an under-used technique. In addition to any screening, softening, ecological or other contributions it can keep the public away from the base of faces or high slopes and help to contain rockfall. Where planting on the floor at the base of final slopes had been used, it was particularly successful.

The final planting technique used in the visited quarries was the soiling, seeding, natural revegetating or hydraulic seeding of faces. This was used in just over half of the quarries but was almost always an *ad hoc* technique rather than part of a planned approach.

After planting, the most used technique was the tipping of material on benches/against faces. Almost all quarries tipped materials specifically for restoration with 40% of those visited totally burying some lower benches with tipped material. As all quarries generate waste materials these must be disposed of; there is therefore an incentive to find a disposal site. This is becoming more significant since the impact of the Aggregates Levy is reducing the sale of low quality aggregates. However, in the

Quarry No.	RECORD 1		RECORD 2		RECORD 3		RECORD 4 / A		RECORD 4 / B		RECORD 4 / C		SITE RANKING					
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	0	1	2	3	4	5
1		■		■	■			■		■	■							■
2		■		■	■			■		■	■							■
3	■		■			■	■		■			■	■					
4		■		■		■		■		■		■				■		
5		■		■		■		■		■		■				■		
6		■		■		■		■		■		■				■		
7		■		■	■			■		■	■							■
8	■		■			■		■		■	■				■			
9		■		■	■			■		■	■							■
10		■		■		■		■		■		■				■		
11	■		■			■	■			■		■		■				
12	■		■			■	■		■			■	■					
13		■		■	■			■		■	■							■
14		■		■	■			■		■	■							■
15	■		■			■	■		■			■	■					
16		■		■	■			■		■	■							■
17		■		■	■			■		■	■							■
18	■		■			■	■		■			■	■					
19		■		■	■			■		■	■							■
20		■		■	■			■		■	■							■
21		■		■	■			■		■	■							■
22		■		■	■			■		■	■							■
23	■		■			■	■		■			■	■					
24	■		■			■		■		■	■				■			
25	■		■			■	■		■			■	■					
26		■		■	■			■		■	■							■
27	■		■			■	■		■			■	■					
28	■		■			■	■		■			■	■					
29	■		■			■	■		■			■	■					
30	■		■			■	■		■			■	■					
31	■		■			■	■		■			■	■					
32		■		■	■			■		■	■							■
33	■		■			■		■		■	■				■			
34	■		■			■	■		■			■	■					
35		■		■	■			■		■	■							■
36		■		■	■			■		■	■							■
37		■		■	■			■		■	■							■
38		■		■	■			■		■	■							■
39		■		■	■			■		■	■							■
40	■		■			■		■		■	■				■			
41		■		■	■			■		■	■							■
42		■		■		■		■		■		■				■		
43		■		■	■			■		■	■							■
44	■		■			■	■		■			■	■					
45	■		■			■	■		■			■	■					

Site ranking based on net contribution to the landscape.

0 Negative short and long term.
1 Negative short term, neutral long term.
2 Negative short term, positive long term.
3 Neutral short term, neutral long term.
4 Neutral short term, positive long term.
5 Positive short and long term.

Table 7.1 Summary of Landscape Survey Results ***(Continued over)***

Quarry No.	Quarry Setting	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Hillside				■								■	
2	Hilltop	■			■			■				■	■	■
3	Hilltop	■					■					■		
4	Hilltop	■		■	■					■	■	■	■	
5	Hilltop				■							■	■	
6	Hilltop	■			■	■					■			■
7	Valley bottom	■			■			■				■	■	■
8	Hilltop	■			■					■	■	■	■	■
9	Valley bottom/hillside				■			■				■	■	■
10	Hilltop/Hillside				■						■	■		■
11	Hilltop											■	■	
12	Coastal/hillside	■			■				■			■	■	■
13	Hilltop	■			■		■				■			■
14	Hilltop	■			■		■				■			■
15	Hilltop				■						■			
16	Valley bottom	■			■							■	■	
17	Hilltop				■		■			■	■	■		■
18	Hillside		■	■	■									■
19	Valley bottom			■	■								■	
20	Hillside/hilltop				■	■		■				■		■
21	Hillside/hilltop		■		■						■	■		■
22	Hilltop/hillside				■								■	
23	Hillside/hilltop	■	■	■	■									
24	Hilltop/hillside	■		■	■		■	■						
25	Hillside		■		■									
26	Valley bottom	■		■	■							■	■	■
27	Hillside/hilltop			■	■							■	■	
28	Hillside	■		■	■	■						■	■	
29	Hillside	■	■	■	■	■			■		■	■	■	■
30	Coastal	■			■	■								
31	Hillside	■			■							■	■	■
32	Hillside	■		■			■				■	■	■	■
33	Hillside	■									■	■	■	■
34	Hillside		■	■	■									
35	Hillside/hilltop	■		■	■						■	■	■	
36	Coastal					■							■	
37	Coastal	■				■							■	
38	Coastal	■				■							■	■
39	Hillside/hilltop		■	■	■						■			■
40	Hilltop/hillside	■		■	■						■	■		■
41	Valley bottom				■			■						
42	Hillside				■						■	■	■	■
43	Hilltop	■		■	■						■		■	
44	Hillside	■			■							■	■	
45	Coastal			■								■		

Specific Techniques

RIM

1 Roll over
2 Nibbling
3 Bunds and mounds
4 Planting
5 Removal of features
6 Retention of features
7 Re-planning of variation in rim
8 Remedial work

FACE

9 Scaling of faces
10 Variation
11 Tipping against face
12 Soiling / grassing / hydraseeding
13 Planting against face
14 Use / awareness of colour
15 Avoiding blast markings on
16 Netting / matting
17 Encouraging fauna
18 Preservation of important geology

BENCH

19 Total removal by tipping
20 Partial tipping on benches
21 Avoiding repetition
22 Planting / vegetation
23 Rockfall containment
24 Maintaining access

FLOOR

25 Fill placement
26 Planting on floor / base
27 Water
28 Gentle planar slope / floor

Quarry No.	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1						■									
2						■		■	■		■	■	■	■	
3												■	■		
4							■		■			■			
5							■			■	■	■	■	■	
6							■	■	■				■	■	
7						■		■	■			■	■		
8						■	■	■	■			■	■	■	
9						■						■	■		
10							■		■		■		■	■	
11						■	■				■				
12						■	■		■			■	■	■	
13							■		■			■	■	■	
14									■				■	■	
15	■						■		■						
16	■					■	■						■	■	
17				■	■							■	■		
18							■	■	■	■				■	
19	■					■			■			■	■		
20												■	■		
21		■					■		■						
22												■	■	■	
23							■		■		■				
24						■	■		■			■	■	■	
25	■						■								
26						■	■		■			■	■	■	
27												■	■		
28												■			
29			■									■	■		
30							■		■					■	
31						■	■								■
32						■	■	■	■		■	■	■		
33	■											■			■
34				■	■										
35						■	■	■	■			■	■		
36													■		
37						■	■	■	■				■		
38															
39	■						■		■	■	■			■	
40			■			■						■			
41						■									
42						■	■		■						
43						■	■	■	■		■	■			
44						■	■		■				■	■	
45							■					■	■		

Specific Techniques

RIM

1 Roll over
2 Nibbling
3 Bunds and mounds
4 Planting
5 Removal of features
6 Retention of features
7 Re-planning of variation in rim
8 Remedial work

FACE

9 Scaling of faces
10 Variation
11 Tipping against face
12 Soiling / grassing / hydraseeding
13 Planting against face
14 Use / awareness of colour
15 Avoiding blast markings on
16 Netting / matting
17 Encouraging fauna
18 Preservation of important geology

BENCH

19 Total removal by tipping
20 Partial tipping on benches
21 Avoiding repetition
22 Planting / vegetation
23 Rockfall containment
24 Maintaining access

FLOOR

25 Fill placement
26 Planting on floor / base
27 Water
28 Gentle planar slope / floor

majority of visited quarries some waste materials were tipped where they did not contribute to the final restoration of slopes or where they would need to be double handled in order to make such a contribution. While estimating waste generation cannot be exact, a pre-planned sequential series of restoration areas can be decided such that almost all materials are moved once. This is both efficient and cost-effective. It has the additional benefit of allowing earlier establishment of any planting perhaps with smaller planting stock (itself both efficient and cost-effective).

The tipping of waste materials was a widely used and successful technique. It was at its most successful where sinuous shapes were created and less effective where there was the tendency to create broadly triangular section tipping on benches/against faces. Rarely in the English landscape do such rectilinear forms occur and an opportunity has been lost to create more sinuous forms. Rigid tipping (as with excessive rim planting) tends to emphasise linearity and repetition rather than to soften and integrate. Variable bench tipping which follows bedding or folding in the face looks far more natural.

Although not always achievable because of lack of waste material generation, the most successful visited quarry restorations had concentrated tipped materials in at least one side of the quarry such that the surrounding landscape was brought down into the quarry. Nothing destroys the "hole-in-the-ground" appearance more than this concentration of tipped materials; almost always it is preferable to the piecemeal scattering of materials on various benches around the quarry even with extensive planting. The tipping of materials is of paramount importance; vegetation or human land uses may come and go but the restored landform may well be for the very long term.

In half the visited quarries attempts had been made to roll over the *in situ* overburden on the rim; this was a very successful technique often occurring at a very visible part of the quarry. This, too, integrates the surrounding landform and, when coupled with extensive sympathetic tipping leads to a quality long term restored landform.

Fig. 7.5 The ultimate objective - a major quarry assimilated into its surrounding landscape

These are based on the findings of the visits to 55 quarries most of which were or had been SME operations (see Table 8.1).

The visits were to a wide range of geotechnical settings and included both working quarries and to some that had finished recently. Table 8.1 lists the quarries (not identified) and the findings in terms of slope geometry and the condition of the final slopes. Some operational faces were inspected but are not included in this table.

Most of the quarries visited had no major instability but it was present or had previously occurred and been rectified at 20% of the quarries. Rockfall on the other hand was present as a moderate to high risk at 80% of the quarries. Major large instability commonly causes significant operational or environmental problems but very rarely serious injuries or death whereas rockfall is a far more important source of serious or fatal injuries.

Large slope failures

Of the larger slope failures most were attributable to inclined bedding and the intercalated clay bands within the limestones or sandstones affected. One related to sliding on a boundary fault defining the limits of the working area and two were in soil type materials (mineral and overburden). Clearly the working of inclined bedded limestones with clay bands is a matter where the SME operators should be extremely cautious. They should seek advice if their workings are likely to give rise to undercutting of strata with dips as flat as 7 to 8° where clay bands are present and 20 to 30° even if clay bands are positively not known to be present.

Rockfall

Rockfall is a far more extensive hazard for final quarry faces and is present in quarries of all the different rock types used for aggregates. In the quarries visited the greatest proportion of High Rockfall Risk sites were sandstone quarries and metamorphic rock quarries. Very few quarries employed any face scaling and only a few provided positive rockfall protection as toe bunds or total face buttressing. Of the hard rock quarries visited 33% had only a single rock face with no benching. Of these 60% had a Medium or High Rockfall Risk. The majority of rock quarries (55%) had benching; the benches ranged in width from 3 to 10m and showed no relationship to the height of the bench face above. The majority were 5m or less in width. However about half the sites where benching was present had some form of edge protection on the benches. Assessments of rockfall risk showed that for 15m high bench faces only bench widths of 7m or more with edge protection provided good rockfall protection to those below the bench. Only moderate or poor protection was provided by benches of 5m or less even with edge protection.

Basically for long-term rockfall protection a toe bund needs to be positioned and sized according to the risks. Fencing in combination with toe bunding gives the best protection.

Bench face heights were similarly variable. One final limestone face was being restored to a series of 1 to 1.5m high steps. 40% of rock quarries had some benches of 30m or more in height and 14% were 45m or higher. To some extent this represents the situation before the impact of the Quarries Regulations 1999. Indeed some of the quarries visited have not worked since the end of the century and reflect a decision on the part of the owners and operators not to continue quarrying in the context of the new regulations. However bench removal was in progress at some quarries visited; this is a truly hazardous operation and can have regrettable consequences for safety during after-use if not for working. Fortunately many quarries are now working with 10 to 15m bench heights and there appears to be a shift in some workings to concentrate on 12m bench heights having regard to the ability to scale faces more readily.

Smaller slope failures

These are more frequent than large scale collapses, but usually less hazardous than the rockfall if the latter is taken to include falls of ground up to 10m³ in size. Ground movements of 10 to 100m³ appeared to have occurred at some time on all the quarries visited and movements of over 1000m³ on a number of sites. In spite of precautions most firms regard these small scale failures as inevitable at some stage during operations. The important approach during operation is to have in place good excavation and loading rules that prevent

Quarry No.	Quarry Setting	SSSI	Geology	Lithology	Inclined or Sub-horizontal footwall	Ground preparation	No. of benches (faces)
1	Hillside		Carboniferous	Limestone	Inclined	BL	n/a (1)
2	Hilltop		Carboniferous	Limestone	Inclined	BL	3 (4)
3	Hilltop		Carboniferous	Limestone	Sub-horizontal	BL	n/a (1)
4	Hilltop		Jurassic	Limestone	Sub-horizontal	R	5 (6)
5	Hilltop	SSSI	Permian	Limestone	Sub-horizontal	BL	n/a (1)
6	Hilltop		Igneous	Granite	Massive	BL	5 (6)
7	Valley bottom		Cretaceous	Sand & Gravel	Sub-horizontal	NGP	n/a (1)
8	Hilltop	SSSI	Jurassic	Limestone	Sub-horizontal	NGP	4 (5)
9	Valley bottom/hillside		Permian	Limestone	Sub-horizontal	BL	n/a (1)
10	Hilltop/Hillside		Carboniferous	Sandstone	Inclined	BL	1 (2)
11	Hilltop		Carboniferous	Sandstone	Sub-horizontal	NGP	n/a (1)
12	Coastal/hillside		Igneous	Gabbro	Massive	BL	2 (3)
13	Hilltop		Igneous	Granite	Massive	BL	n/a (1)
14	Hilltop		Igneous	Granite	Massive	BL	n/a (1)
15	Hilltop		Igneous	Granite	Massive	BL	n/a (1)
16	Valley bottom		Jurassic	Sand & Gravel	Sub-horizontal	NGP	n/a (1)
17	Hilltop	SSSI	Jurassic	Limestone	Sub-horizontal	BR	n/a (1)
18	Hillside		Carboniferous	Limestone	Sub-horizontal	BL	4 (5)
19	Valley bottom		Quaternary	Sand & Gravel	Sub-horizontal	NGP	n/a (1)
20	Hillside/hilltop		Carboniferous	Limestone	Inclined	BL	n/a (1)
21	Hillside/hilltop		Devonian	Limestone	Inclined	BL	2 (3)
22	Hilltop/hillside		Igneous	Dolerite	Massive	BL	n/a (1)
23	Hillside/hilltop		Carboniferous	Limestone	Inclined	BL	2 (3)
24	Hilltop/hillside		Carboniferous	Limestone	Sub-horizontal	BL	2 (3)
25	Hillside		Carboniferous	Limestone	Sub-horizontal	BL	2 (3)
26	Valley bottom		Quaternary	Sand & Gravel	Sub-horizontal	NGP	n/a (1)
27	Hillside/hilltop	SSSI	Igneous	Basalt	Massive	BL	n/a (1)
28	Hillside	SSSI	Permian	Limestone	Sub-horizontal	BL	n/a (1)
29	Hillside		Carboniferous	Limestone	Sub-horizontal	BL	n/a (1)
30	Coastal	SSSI	Metamorphic	Dolerite	Massive	BL	6 (7)
31	Hillside	SSSI	Silurian	Limestone	Inclined	BL/BR	6 (7)
32	Hillside		Carboniferous	Limestone	Sub-horizontal	BL	n/a (1)
33	Hillside		Carboniferous	Limestone	Inclined	BL	n/a (1)
34	Hillside		Carboniferous	Limestone	Inclined	BL	n/a (1)
35	Hillside/hilltop		Jurassic	Limestone	Sub-horizontal	BL	n/a (1)
36	Coastal		Metamorphic	Metasediments	Inclined	BL	n/a (1)
37	Coastal		Metamorphic	Metasediments	Inclined	BL	n/a (1)
38	Coastal		Metamorphic	Metasediments	Inclined	BL	n/a (1)
39	Hillside/hilltop		Devonian	Limestone	Inclined	BL	5 (6)
40	Hilltop/hillside	SSSI	Carboniferous	Limestone	Sub-horizontal	BL	2 (3)
41	Valley bottom		Quaternary	Sand & Gravel	Sub-horizontal	NGP	n/a (1)
42	Hillside		Carboniferous	Limestone	Sub-horizontal	BL	2 (3)
43	Hilltop		Carboniferous	Limestone	Inclined	BL	4 (5)
44	Hillside		Devonian	Sandstone	Inclined	BL	2-4 (3-5)
45	Coastal		Igneous	Gabbro	Massive	BL	2 (3)
46	Hilltop		Carboniferous	Limestone	Inclined	BL	4 (5)
47	Hillside		Carboniferous	Limestone	Inclined	BL	5 (6)
48	Hillside		Carboniferous	Sandstone	Sub-horizontal	BL	5 (6)
49	Hillside		Carboniferous	Limestone	Sub-horizontal	BL	7 (8)
50	Hilltop/Hillside		Carboniferous	Limestone	Inclined	BL	1 (2)
51	Hilltop/Hillside		Igneous	Granite	Massive	BL	3-4 (4)
52	Hilltop/Hillside		Carboniferous	Limestone	Inclined	BL	1 (2)
53	Coastal		Igneous	Gabbro	Massive	BL	n/a (1)
54	Hilltop		Permian	Limestone	Sub-horizontal	BL	2-3 (4)
55	Valley bottom		Cretaceous	Sand & Gravel	Sub-horizontal	NGP	0-3 (1-4)

BL Blast
R Rip
BR Break
NGP No ground preparation

Table 8.1 Summary of geotechnical findings
(Continued over)

Quarry No.	Bench widths (m)	Bench face height (m)	Bench face angle (°)	Overall slope height (m)	Overall slope angle (°)	Type and effectiveness of rockfall containment	Type of instability - major or (minor)	Rockfall Hazard	Final or restored slopes hazard rating
1	n/a	15-30	45	15-30	45	n/a	(PL)	M	MSH
2	<3	15	30	45-60	35	B - G	PL (C)	L	MSH
3	n/a	15-30	65	15-30	65	None	(T)	M	NSH
4	<2	1-1.5	50	0-15	30	B - M	(C)	L	LSH
5	n/a	30-45	26-80	30-45	26-80	TB - G	(W)	M-H	MSH
6	<3	10	70	45-60	65	B - M	(W, T)	M	MSH
7	n/a	15-30	30	15-30	30	n/a	(C)	n/a	NSH
8	3-7	1-2.5	60	0-15	20-30	B - G	(W)	L-M	NSH
9	n/a	0-15	65	0-15	65	TF - M	(W, T)	L-M	NSH
10	5	10	80	15-30	45	B - P	PL (W)	H	HSH
11	n/a	15-30	30	15-30	30	n/a	(C)	L	NSH
12	<2	10-20	70	30-45	65	B - P	(W)	M	MSH
13	n/a	0-15	80	0-15	80	None	(W, T)	M	MSH
14	n/a	15-30	80	15-30	80	None	(W, T)	M	MSH
15	n/a	30-45	80	30-45	80	None	(W, T)	H	HSH
16	n/a	0-15	30	0-15	30	n/a	(C)	n/a	NSH
17	n/a	0-15	45-70	0-15	45-70	None	(W)	M	NSH
18	<5	10-15	80	45-60	65	B, EP - M	(W, T)	H	MSH
19	n/a	0-15	20	0-15	20	n/a	(C)	n/a	NSH
20	n/a	30-45	26	30-45	26	TF - G	(T)	L-M	LSH
21	<5	15-20	60-80	45-60	45-60	B, EP - M	PL (W,PL)	M	MSH
22	n/a	0-15	80	0-15	80	None	(T)	L-M	NSH
23	<3	20	70	60+	65	B - P	(T)	H	MSH
24	<3	20	70	45-60	65	B - P	(C, T)	H	MSH
25	<3	20	70	45-60	65	B, EP - M	(C, T)	H	MSH
26	n/a	0-15	30	0-15	30	n/a	(C)	n/a	NSH
27	n/a	15-30	80	15-30	80	None	(T)	M	LSH
28	n/a	15-30	70	15-30	70	None	(T, W)	H	HSH
29	n/a	15-60	80-85	45-60	70-80	None	C	L-M	MSH
30	1-10	10-40	60-80	60+	45-60	B - P	(W, T)	H	MSH
31	3-5	6-8	65-70	45-60	45-55	None	PL	M	MSH
32	n/a	15-30	70	15-30	70	None	(T)	H	LSH
33	n/a	15-30	70	15-30	70	TB - M	PL	M	MSH
34	n/a	15-30	60	15-30	60	None	(PL)	H	LSH
35	n/a	15-30	26-30	15-30	26-30	n/a	(W, C)	L-M	NSH
36	n/a	30-45	70	30-45	70	None	(W, T)	H	MSH
37	n/a	30-45	70	30-45	70	None	(W, T)	H	MSH
38	n/a	45-60	70	45-60	70	None	(W, T)	H	MSH
39	<3	10	80	60+	65	B - P	PL	M	MSH
40	<7	15-20	70	45-60	65	B, EP - G	(W)	M	LSH
41	n/a	15-30	30	15-30	30	n/a	(C)	n/a	NSH
42	<7	15-25	30-80	30-45	30-65	B, EP - G	(C)	M	NSH
43	5	20	45	60+	60	B, EP - G	(W, PL)	L-M	LSH
44	3	15-60	45-60	60+	45-60	B - P	PL (W, PL, T)	H	HSH
45	<7	15-30	60-80	30-45	45	B, EP - M	(W, T)	M	LSH
46	<7	10-40	70-80	60+	60	B, EP - G	BP (T)	H	MSH
47	<3	10-15	30-70	60+	45	B - M	PL (T)	H	MSH
48	<3	10-20	70-80	60+	45	B, EP - M	(T)	H	MSH
49	<3	10-20	70	60+	65	B - P	(T)	H	HSH
50	<5	10-15	70	15-30	45-60	B, EP - G	PL (T)	M	LSH
51	>7	10-15	60	15-30	45	B, EP - G	(T)	H	HSH
52	<3	10-15	70	15-30	65	None	BP (T)	M	HSH
53	n/a	0-15	70	0-15	70	None	(W, T)	M	NSH
54	>5	10-15	70-90	30-45	45	B, EP - G	(T)	M	MSH
55	<3	4-30	26-70	30	26-45	n/a	C	n/a	LSH

B Bench
EP Edge protection
TB Toe bund
TF Toe fence
P Poor
M Moderate
G Good

PL Planar
BP Bi-planar
W Wedge
SL Slab
C Circular
T Toppling

L Low
M Moderate
H High

HSH High significant hazard
MSH Moderate significant hazard
LSH Low significant hazard
NSH Non significant hazard

Table 8.1 Summary of geotechnical findings *(Continued)*

persons working close to where collapses may occur. Many of the smaller slips can of course be avoided by changes in face alignment (but not necessarily final faces if the positions are fixed).

The most common types of small failures were toppling and wedge collapses. Toppling had occurred or appeared likely in 90% of the igneous quarries visited, in part due to the columnar nature of some of the jointing. Of the limestone and sandstone quarries visited it had also occurred or was present in 45 and 50% of the sites respectively. Circular or curvilinear failures occurred in 50% of the sandstone quarries (in superficial deposits or backfilled materials) and most of the sand and gravel workings.

Fig. 8.1 Clean, final, low bench height slope faces excavated by breaker in an SSSI (Note access provided by benches to inclined strata)

Review

Although the overall impression of the state of final slopes in SME quarries is perhaps unsatisfactory, many of the slopes relate to previous planning permissions before stability became a material planning consideration and before the safety of excavated slopes was clearly regulated by legislation. In summary there are some obvious improvements that can be made:

- Final faces should be scaled at the time of removing the final blast pile when access is assured.
- Final faces if benched should have benching of adequate width for safety if rockfall is likely, as well as to permit on-bench planting and safe access. Benches should therefore generally be 7m or more in width with 15m high bench faces.
- Bench heights should not exceed 15m and ideally should be 10 to 12m to permit safe scaling.
- Buttressing or partial bench face buttressing can be beneficial provided the fill:
  - is secure,
  - can be placed safely,
  - is protected from surface water erosion,
  - is suitable for planting or grassing and consistent with intended after-uses,
  - accommodates unforseen waste,
  - can facilitate access to geological sites.
- All quarries in inclined strata should be very carefully checked for undercutting and worked to avoid this or to permit prompt buttressing.
- Rockfall comprises the main hazard in SME quarries (and those of others)
- Hazard appraisals should comprise part of a document file at the completion of a quarry and on its sale or return to the landowner/mineral owner.
- Mineral owners should consider a requirement to enter into agreements/bonds with the operators to ensure the recovery of the cost of remedial works in the event of slope failure within a period (say 7 years) of the completion of quarrying.
- Operators (and MPAs) should be assured

that there is sufficient quarry waste for the intended final restoration works including buttressing to final slopes.

- Most aggregate quarries employ blasting for ground preparation. Blast holes should be aligned to promote secure slopes especially at the site limits. Different, less damaging blast hole loading should be considered at the limits of a quarry.

- Vertical blast holes may be advisable in some flat lying strata with vertical jointing since rockfall is unlikely to be projected away from the toe of the slope.

- Edge protection is increasingly widely used on SME quarries owing to the rigorous enforcement of the 1999 Quarries Regulations. This helps with rockfall protection and can be integrated with the buttressing of higher bench faces and/or the placement of growing media for on-bench planting.

- Some MPAs could and should give closer attention to the security of final slopes. As a general matter, safety should be paramount and items such as rockfall protection bunds or buttresses against faces of questionable stability should not be rejected on landscape grounds, (especially if the features in question can only have been seen from the air).

- English Nature needs to consider the significance of the new safety culture that exists in the quarrying sector. Access to many quarry faces is inherently unsafe and should not be encouraged. There are a variety of measures that may be implemented to protect the most important features, but these are expensive. Except where required in the context of planning gain on sites elsewhere, operators cannot be required to provide these measures at their SSSIs. However owners need to be aware that they may find themselves with legal liabilities even if trespassers are injured at their sites due to falls of ground.

- Better preservation of final quarry faces for conservation is likely to be achieved if the lengths of face to be protected are kept to a minimum rather than comprising all the final faces.

- The height of long-term rock slopes for SSSIs should not significantly exceed 5m in bedrock or 2m in weak rocks and soils, including sand and gravel, if direct access is to be permitted to quarry faces. Formal hazard appraisals should be made at all SSSIs every 2 to 5 years.

In general the Quarries Regulations are improving the safety of both operating and final quarry faces. The greatest need is to scale faces safely and consistently.

Fig. 8.2 Low benching of rock for long term safe access to a geological SSSI

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Proformas used in the Survey

These are included since they may be used by SME firms or their advisors to estimate and assess the conditions that exist or may exist with proposed or permitted final slopes in their landscape setting.

Hazard appraisal

Definitions

The following hazard appraisal forms are intended as a formal aid to the appraisal of excavations and tips as required under Regulation 32 of the Quarries Regulations 1999. They can be used to identify all excavations and tips where a *significant hazard* exists. (The term *hazard* in this case means *the potential to cause harm to the health and safety of any person*). Hazards may result from the movement or collapse of excavations or tips onto, or from beneath places where persons may be present whether inside or outside the curtilage of the quarry.

Excavations include all working or worked faces and access cuttings whether active or not regardless of whether they comprise bedrock, sand and gravel, overburden or reworked waste materials.

Tips include all solid accumulations of wastes and also comprise stockpiles of minerals, soil or spoils for subsequent use, screening or amenity banks and backfill returned to the quarry void or used to buttress the final face. It is a requirement of the 1999 Regulations that all such structures are designed, constructed, operated and maintained to avoid risks to health and safety. In defining a significant hazard the Approved Code of Practice with the 1999 Regulations draws specific attention to excavations and tips above certain sizes *etc*. These larger, higher or steeper *etc*. excavations and tips are known as Notifiable Excavations and Tips.

The following lists cover the structures (solid tips and excavations) which are to be treated as *significant hazards:*

Stronger rocks where:

- Individual slopes (bench faces) are more than 15m high, or
- overall benched slopes are steeper than 1 in 1 (45°) and between 15 and 30m high, or
- slopes are more than 30m high, or
- there are other factors that indicate a significant potential for harm.

Strong rocks typically require ripping, breaking or blasting

Weaker rocks and soils where:

- Slopes are more than 7.5m high and the slope is steeper than 1 in 2 (27°), or
- slopes are more than 30m high, or
- there are other factors that indicate a significant potential for harm.

Weaker rocks or soils do not require ripping *etc*. for excavation.

Solid Tips that:

- Cover more than 10,000m², or
- are more than 15m high, or
- are founded on land sloping at more than 1 in 12, or
- have other features that indicate a significant potential for harm.

The other factors noted above typically comprise adverse ground conditions, or indications of instability or interaction between for example a tip and an excavation, or indications that the danger of movement or failure of the structure is significant.

Steps in appraisal

It is the duty of the appointed competent person at each of an operator's quarries or areas to undertake the inspection of the excavations (and tips) in a quarry and to identify the presence of significant hazards. It is important to carefully visit each section of excavation (or relevant tip). This is work frequently given to the quarry foreman since he is often responsible for the daily and weekly inspection of working places. Hence quarry managers or foremen could complete each section of the *pro forma*. It is not necessary for this work to be done by a geotechnical engineer. The following tables are to be completed and the position of each slope examined is to be shown on the latest available quarry plan (scale 1:2500).

There are three tables included:

- Excavations in stronger rocks.
- Excavations in weaker rocks and soils and sand and gravel extraction.
- Solid tips and stockpiles.

A ranking/scoring system is incorporated so that significant hazards are apparent and it is possible to ascertain those significant hazards as defined above which are most critical.

Each of the tables is divided into three parts A, B and C. A covers the geometry of the structures, and B covers items which might render the excavation or tip a significant hazard even though the geometry *etc* is such that it appears not to be a significant hazard. Part C covers the danger from the structure *i.e.* how many people are at risk from a collapse. The product A x C or B x C gives a guide to the *relative* significance of hazards. The scoring is explained on each table. The most ill defined of matters relates to Part B. This protocol works on the basis that indications of instability or the presence of other listed conditions are considered when assessing the presence or otherwise of a significant hazard outside the categorisation in Part A.

Geotechnical Assessment

As a result of this work those excavations (and tips) that require a *geotechnical assessment* are clearly identified and steps can then be put in motion for this work to be undertaken. Experience shows that excavations with scores of less than 5 (although technically a significant hazard) are frequently not found to be such when assessed by a geotechnical specialist. Scores of 5 to 10 are less certain and some slopes are likely to require formal geotechnical assessment. Scores above 10 invariably require such an assessment. A geotechnical assessment if indicated has to be undertaken and signed by a geotechnical specialist who completes it in accordance with Regulations 33 and 34 and Schedule 1 of the Quarries Regulations 1999. The Regulations require repeat geotechnical assessments at least every two years.

However, if the conclusion of this assessment is that the excavation or tip is not a significant hazard or where by virtue of proposed *and* completed works, the excavations or tips may be removed from the significant hazard category (*e.g.* it is so unlikely to collapse that the potential to cause harm to health and safety is remote or the risk of injury from any collapse is trivial) the structure returns to the hazard appraisal category. In these circumstances it is to be appraised by quarry staff at a frequency determined by the geotechnical specialist who undertook the geotechnical assessment. This should not be less frequent than every two years.

Following a geotechnical assessment, it is necessary, if the geotechnical specialist has confirmed that the hazard is significant, that the HSE is so advised within 30 days.

HAZARD APPRAISAL FORM

Sand and gravel excavations
Weak rock and engineering soil excavations [1]

D = date[2] S = score[3]	D:	S
Name/no. of excavation		
Position shown with name/no.on appended plan Yes/No		
PART A ***Geometry of excavation***		
Slope height m		
Slope height exceeds 30m Yes/No		
Overall slope angle 1 in x		
Slope height exceeds 7.5m and is steeper than 1 in 2 (27°) Yes/No		
TOTAL		
PART B ***Inspection of individual faces*** **(Denote North – N, South – S, *etc*).**		
Distress/potential problems behind the crest (ponding of water, cracking, settlement) Note whether face N, S, *etc*. Yes/No		
Distress on slope face (bulging, cracking, slumping, water discharge). Note whether face N, S, *etc* Yes/No		
Distress in front of excavation (toe heave, water issues). Note whether face N, S, *etc*. Yes/No		
Other grounds for concern over future stability[4]. Note whether face N, S, *etc*. Yes/No		
TOTAL		
PART C ***Danger from slope***		
Persons working above or below slope – Regularly/Occasionally/ Never		
Plant/Buildings below slope – describe		
Persons or installations at risk off-site – Regularly/Occasionally/Never		
TOTAL		
Hazard ranking **Totals A x C**		
Hazard ranking **Totals B x C**		
General Findings[5]		
Action to be taken [6]		
Geotechnical assessment required[7] Yes/ No Date by which assessment required Date for next hazard appraisal	Yes ↓	No ↓ ↓

Signed …………………………………… Date …………….. Other persons notified – name/position…………………………………………………

Action Taken [9]

Signed …………………………………… Date …………….. Other persons notified – name/position…………………………………………………

Notes

1 Weak rock and engineering soils (BS5930) may be taken as are those materials which can be excavated without ground preparation (blasting/heavy ripping. They include sands and gravels and overburden of superficial deposits

2 Date – enter date of the inspection after D.

3 For ranking the hazard, score in blank section of Column S as follows:-

PART A	Score 1 for Yes. Score 0 for No. Maximum total score 2 is a very significant hazard **, any score implies a Notifiable Excavation.**
PART B	Score 1 for any sign of distress or ground for concern and 0 for no obvious distress *etc*. Maximum total score 4 for any individual slope face.
PART C	Score 3 if one or more persons are regularly at risk on a site and score 2 if persons are occasionally at risk. Score 1 if no-one is at risk. Maximum total score 6.
THEN	*Multiply* totals of Parts A and C to identify the most important of the *significant hazards.* Maximum score 12, **minimum score 2 which is still a Notifiable Excavation requiring a geotechnical assessment.** *Multiply* totals of Parts B and C to identify **hazards which may be taken to be *significant* if the score is 3 or more. Such excavations are Notifiable Excavations.** Maximum score 24. Minimum 2.

4 See separate list below:-
Items which may give rise to concern over future stability of slopes in sand and gravel, overburden, clay or similar materials include:

- Where the face height exceeds the reach of the excavator
- Where surfaces on which slipping might occur are present in the face, *e.g.* layers of peat, clay or a steep rock -head slope inclined into the excavations.
- Where previous excavations or mineral workings are present behind or beneath the quarry face.
- Where bedrock excavation does not leave a rockhead bench or where bedrock movements may undercut the overlying materials.
- Where wave action or other activities may undercut a face *e.g.* wet gravel workings
- Instability elsewhere in similar materials
- Surcharging slope crests by heavy/vibrating plant.

5 Give overall findings *e.g.* geotechnical assessment required or no significant hazard followed by reasons *e.g.* small structure, no instability, no-one at risk.

6 Complete for inclusion in health and safety document. Include all structures listed.

7 Circle which applies. If 'No' state date of next appraisal (not more than 2 years).

8 State date by which the assessment is to be completed.

9 Report any instructions/requests for remedial works and the date of completion

OTHER OBSERVATIONS
Has the structure been designed Yes/No
If yes, has it been built according to design Yes/Not Yet/No

HAZARD APPRAISAL FORM

Excavations in stronger rocks[1]

D = date[2] S = score[3]	D:	S
Name/no. of excavation		
Position shown with name/no.on appended plan Yes/No		
PART A ***Geometry of slope***		
Height of bench faces m		
Bench faces exceed 15m Yes/No		
Overall slope height m		
Overall slope angle 1 in *x* or degrees		
Slope angle is steeper than 1 in 1 (45°) and the benched slope height is 15-30m Yes/No		
Overall slope height exceeds 30m Yes/No		
TOTAL		
PART B ***Inspection of individual faces*** **(Denote North – N, South – S, *etc*).**		
Distress behind the slope face or on benches (cracking, settlement, ponding of water) Note whether face N, S, *etc*. Yes/No		
Distress on slope face (bench faces) (cracking, slumping, active displacements and rockfall, water discharge). Note whether face N, S, *etc* Yes/No		
Distress in front of slope (toe heave, water issues). Note whether face N, S, *etc*. Yes/No		
Other grounds for concern over future stability[4]. Note whether face N, S, *etc*. Yes/No		
TOTAL		
PART C ***Danger from excavation***		
Persons working above or below slope – Regularly/Occasionally/Never		
Plant/Buildings below slope – describe		
Persons or installations at risk off-site – Regularly/Occasionally/Never		
TOTAL		
Hazard ranking **Totals A x C**		
Hazard ranking **Totals B x C**		
General Findings[5]		
Action to be taken [6]		
Geotechnical assessment required[7] Yes/ No	Yes ↓	No ↓
Date by which assessment required		↓
Date for next hazard appraisal		

Signed …………………………………… Date …………….. Other persons notified – name/position…………………… ……………………………

Action Taken [9]

Signed …………………………………… Date …………….. Other persons notified – name/position…………………………………………………

Notes

1 Taken to be all rocks where ground preparation is or may be required; includes Coal Measure, Mercia Mudstone and Middle and Upper Chalk (moderately weak rocks or stronger as defined by BS5390).

2 Date – enter date of the inspection after D.

3 For ranking the hazard score in blank section of Column S as follows:

PART A Score 1 for Yes. Score 0 for No. Maximum total score 3 is a very significant hazard **, any score implies a Notifiable Excavation.**

PART B Score 1 for any sign of distress or ground for concern and 0 for no obvious distress *etc*. Maximum total score 4 for any individual slope face.

PART C Score 3 if one or more persons are regularly at risk on a site and score 2 if persons are occasionally at risk. Score 1 if no-one is at risk. Maximum total score 6.

THEN *Multiply* totals of Parts A and C to identify the most important of the *significant hazards*. Maximum score 18, **minimum score 2 which is still a Notifiable Excavation requiring a geotechnical assessment.** *Multiply* totals of Parts B and C to identify **hazards which may be taken to be *significant* if the score is 3 or more. Such excavations are Not ifiable Excavations.** Maximum score 24. Minimum 2.

4 See separate list below:-
Items which may give rise to concern over the future stability of excavated faces include:

- Old mineral workings/mine workings, behind or beneath the slope.
- Persistent geological surfaces such as fault planes, bedding surfaces and joints inclined into the excavation especially if these exceed 27° (1 in 2) or less if the surfaces are clay lined or clay filled.
- Where slopes in similar materials have collapsed.
- Where excessive loading is proposed behind the crest of the slope by tips or heavy/vibrating plant.
- Where unplanned excavations are proposed or the geology is different from that expected.

5 Give overall findings for each slope face *e.g.* geotechnical assessment required urgently *or* no significant hazard followed by reasons *e.g.* small structure, no instability, no-one at risk.

6 Complete for inclusion in health and safety document. Include all structures listed.

7 Circle which applies. If No state date of next appraisal (not more than 2 years

8 State date by which the assessment is to be completed

9 Report any instructions/requests for remedial works and the date of completion.

OTHER OBSERVATIONS
Has the structure been designed Yes/No
If yes, has it been built according to design Yes/Not Yet/No

HAZARD APPRAISAL FORM

Solid tips and stockpiles

D = date[1] S = score[2]	D:	S
Name/no. of tip		
Position shown with name/no. on appended plan Yes/No		
PART A ***Geometry of tip***		
Approximate area of tip m^2		
Area exceeds $10{,}000m^2$ Yes/No		
Maximum height m		
Maximum height exceeds 15m Yes/No		
Slope of foundation 1 in x		
Gradient steeper than 1 in 12 Yes/No		
TOTAL		
PART B ***Inspection of individual faces*** **(Denote North – N, South – S, *etc*).**		
Distress behind the tip face (cracking, settlement) Note whether face N, S, *etc*. Yes/No		
Distress on tip face (bulging, cracking, slumping, water discharge). Note whether face N, S, *etc* Yes/No		
Distress in front of tip (toe heave, water issues). Note whether face N, S, *etc*. Yes/No		
Other grounds for concern over future stability[3]. Note whether face N, S, *etc*. Yes/No		
TOTAL		
PART C ***Danger from tip***		
Persons working near tip – Regularly/Occasionally/Never		
Plant/Buildings below tip – describe		
Persons or installations at risk off-site – Regularly/Occasionally/Never		
TOTAL		
Hazard ranking **Totals A x C**		
Hazard ranking **Totals B x C**		
General Findings[4]		
Action to be taken [5]		
Geotechnical assessment required[6] Yes/ No	Yes ↓	No ↓
Date by which assessment required		↓
Date for next hazard appraisal		

Signed …………………………………… Date …………….. Other persons notified – name/position…………………………………………………

Action Taken[9]

Signed …………………………………… Date …………….. Other persons notified – name/position…………………………………………………

Notes

1 Date – enter date of the inspection after D.

2 For ranking the hazard score in blank section of Column S as follows:

PART A Score 1 for Yes. Score 0 for No. Maximum total score 3 is a very significant hazard **, any score implies a Notifiable Tip.**

PART B Score 1 for any sign of distress or ground for concern and 0 for no obvious distress *etc*. Maximum total score 4 for any individual slope face.

PART C Score 3 if one or more persons are regularly at risk on a site and score 2 if persons are occasionally at risk. Score 1 if no-one is at risk. Maximum total score 6.

THEN *Multiply* totals of Parts A and C to identify the most important of the *significant hazards.* Maximum score 18, **minimum score 2 which is still a Notifiable Tip requiring a geotechnical assessment.** *Multiply* totals of Parts B and C to identify **hazards which may be taken to be *significant* if the score is 3 or more. Such tips are Notifiable Tips.** Maximum score 24. Minimum 2.

3 See separate list below:-

Items which may give rise to concern over the security of a tip/stockpile include:

- Impeded or damaged culverts beneath structure
- Uncontrolled excavation at toe of structure
- Proposed excavation near toe of structure
- Stockpile height exceeds reach of excavating equipment
- Stockpiles placed on foundations with no prior investigation or stockpiling history
- Oversteep face – exceeds 1 in 1.3 (37.5°)

4 Give overall findings *e.g.* geotechnical assessment required *or* no significant hazard followed by reasons *e.g.* small structure, no instability, no-one at risk.

5 Complete for inclusion in health and safety document. Include all structures listed.

6 Circle which applies. If No state date of next appraisal (not more than 2 years

7 State date by which the assessment is to be completed

8 Report any instructions/requests for remedial works and the date of completion.

OTHER OBSERVATIONS

Has the structure been designed Yes/No

If yes, has it been built according to design Yes/Not Yet/No

Rockfall hazard and risk assessment

The scale and size of most quarries in combination with excavation techniques often results in a rockfall hazard on most active or final slopes. The rockfall assessment sheet is not a detailed rockfall analysis tool, but aims to highlight areas of increased rockfall hazard where further investigation and/or remediation is required.

The rockfall assessment used in this project is based (with amendments) on a *proforma* recently developed [65]. The hazard appraisal considers both the rock mass characteristics as well as the influence of discontinuity orientation, method of excavation and geometrical considerations. An assessment of risk considers the hazard in the context of exposure period by persons below and adjacent to the slope. The system has been successfully used in many quarries throughout England.

The Hazard Appraisal

The condition of the rock mass is considered with respect to intact strength, the rock mass condition and presence of water. The ratings are based on the rock mass ratings which were originally developed to assess the support requirements in underground excavations [7]. In the application of the rockfall appraisal system, the site should be divided into a series of separate structural domains. These domains will coincide with geometric or geological boundaries such as changes in face orientation or major structural features such as faults or the limits of previous workings.

The condition of the rock mass is assessed following the guidance given in the table. Ratings are given for each of the following parameters:

Uniaxial compressive strength: can be assessed by direct measurement or by emperical field test. Typical rock types are included.

RQD: which relates to an index of the quality of the rock mass derived from cored boreholes. It is defined as the percentage of core in lengths in excess of 100mm. Where no core is available RQD may be estimated from the number of discontinuities per unit volume of rock. For a clay free rock, then

$$RQD = 115 - 3.3 \times Jv$$

Where Jv is the sum of the number of joints per unit length for all discontinuity sets present.

Spacing of discontinuities: average discontinuity spacing

Condition of discontinuities: rating relative to the conditions of the discontinuities as described within the table.

Groundwater conditions: rating relative to the presence and amount of water issuing from the face.

Joint orientation: rating accounts for the general orientation and dip angle of discontinuities within the rock mass with respect to promoting instability. The value also depends on the combination of discontinuities present within the rock mass giving rise to *in situ* block shapes described broadly as Blocky (where sides are approximately equidimentional), Tabular (where one dimension is considerably smaller than the other two) and Columnar (where one dimension is considerably larger than the other two). Note: The presence of sedimentological features such as false bedding should also be recorded.

The method of excavation is then taken into account along with the slope geometry *viz*:

Workmanship: the method of excavation impacts on the brokeness of the final face. A low rating is given for clean faces *e.g.* formed by breaker, larger values are appropriate for loose faces formed by blasting. An additional assessment of the bench crest is added which considers any localised overhangs or weathering which may vary in nature from the general face characteristics.

Slope geometry: the bench face height and angle

Each of the factors noted above are then combined to provide a hazard rating for the structural domain face area considered in the following manner:

$$\text{Rockfall Hazard Rating} = \left[100 - (\text{Rock mass rating})\right] \times \left[\text{workmanship rating}\right] \times \left[\text{slope height}/2\right] \times \left[\text{face angle rating}\right]$$

The rockfall hazard is then determined from the tables on the form.

The risk relating to the potential hazard may be assessed by considering the exposure period to the hazard. This is done by multiplying the hazard rating by a risk rating factor which relates to a 1 hour exposure period over fixed intervals. For example, the risk is much reduced when only 1 hour per year is spent in the hazardous areas compared to 1 hour per day. Any significant hazard or risk rating should be addressed to reduce the hazard. This may include exclusion from dangerous areas; where exclusion is not an option then further remediation is required in the form of containment or rockfall trap measures.

The effectiveness of intermediate benches and catch bunds as well as the potential for cascade can also be considered. The hazard rating is then adjusted by applying a reduction factor. Reduction factors relating to any other containment/rockfall trap measures may be derived on a site specific basis.

Rockfall Appraisal and Risk Assessment Sheet
(Continued over)

Site Name : ______________________

Date : ______________________

STRENGTH (material strength)

Field Definition	Compressive Strength(MPa)	Rating	Example
Rocks ring on hammer blows	> 250	15	Basalt, Derbyshire (321MPa)
Core chipped only by heavy hammer blows	100 - 250	12	Andesite, Somerset (204MPa) Carboniferous Limestone Buxton (106MPa)
Broken by heavy hammer blows	50 - 100	7	Magnesian Limestone, Anston (54MPa) *
Broken by light hammer blows	25 - 50	4	Middle Chalk, Hillington (27.2MPa)*
Thin slabs/edges broken by heavy hand	5-25	2	Bath Chalk, Corsham (15.6MPa)*
Can be crumbled by heavy hand pressure	1-5	1	Upper Chalk, Northfleet (5.5MPa)*
Crumbles easily in hand	<1	0	Folkestone Beds Sand, Reigate

* Dry samples

Bench	1	2	3	4	5	6

+

RQD + Js + Jc + GW (Rock mass condition)

Parameter	Range of Values				
Drill Core Quality RQD	90%-100%	75%-90%	50%-75%	25%-50%	<25%
Rating	20	17	13	8	3
Spacing of discontinuities	>2m	0.6-2m	200-600mm	60-200mm	<60mm
Rating	20	15	10	8	5
Condition of discontinuities	Very rough surfaces Not continuous No separation Unweathered rock	Slightly rough surfaces Separation<1mm Slightly weathered	Slightly rough surfaces Separation < 1mm Highly weathered walls	Slickensided surfaces or Gouge<5mm thick or Separation 1-5mm Continuous	Soft gouge>5mm thick or Separation>5mm Continuous
Rating	30	25	20	10	0
Ground water	Completely dry	Damp	Wet	Dripping	Flowing
Rating	15	10	7	4	0

+

JOINT ORIENTATION

General Description	Apparent Dip	Ratings		
		Tabular	Blocky	Columnar
Very favourable	<0	0	0	-5
Favourable	<5	0	-5	-25
Fair	5-10	-5	-25	-50
Unfavourable	10-40	-25	-50	-60
Very unfavourable	>40	-50	-60	-60
Note: Local development of adversely oriented foreset bedding				

Total

100 -

x

WORKMANSHIP

Workmanship	Rating
Sawn / scaled using hydraulic breaker	1
Excavated/dug/natural discontinuity	2
Pre split/low explosive	3
Smooth wall	4
High explosive-some scaling	5
High explosive-average face	6
High explosive-irregular face	7
Crest damage-weathering or blasting / localised overhangs	0-3

a

b

Note if variable between benches

a + b

x

SLOPE HEIGHT(H) ÷ 2

h

h/2

x

GRADIENT RATING

Slope angle	Description	Rating
>80	Free fall	1
70-80	Bouncing	2
55-70	Bouncing	3
45-55	Bouncing	2
<45	Rolling	1

ROCKFALL HAZARD APPRAISAL

ROCKFALL RISK ASSESSMENT

ROCKFALL HAZARD APPRAISAL	
<100	Not Significant
100-1,000	Significant-low
1,000-10,000	Significant-medium
>10,000	Significant-high

x

RISK RATING	
Exposure period for 1 hour	Rating
Hour	1	1
Day	10	0.1
Weekly	50	0.02
Monthly	200	0.005
Annual	2500	0.0004

=

ROCKFALL RISK ASSESSMENT	
<10	Not Significant
10-100	Significant-low
100-1,000	Significant-medium
>1,000	Significant-high

(Continued)

Benching Arrangements

Rockhead bench provision :

Nature of overburden slope :

Bench No. :	1	2	3	4	5	6
Bench Width :						
Individual face angle :						
Edge protection height :						
Condition of bench (clean /choked /overtopping etc.)						

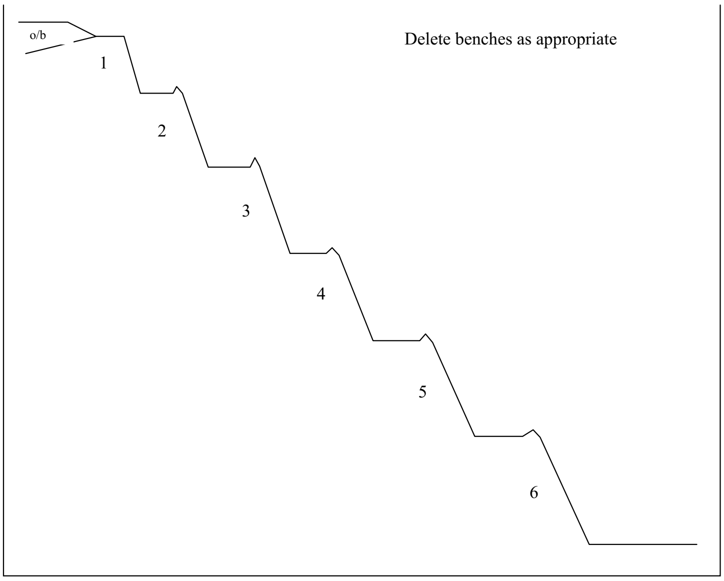
Rockfall cascade potential

Hazard ratin g (individual bench) ( )						
x						
Bench width rating						
x						
Edge protection height rating						
Cascade rockfall hazard rating						
Cumulative cascade hazard rating (ii)		(1)	(1+2)	(1+2+3)	(1+2+3+4)	(1+2+3+4+5)
Cumulative overall rockfall risk rating (i) + (ii)						
OVERALL ROCKFALL RISK ASSESSMENT						

CASCADE RATING

Bench Width (m)	Bund Height (m)	Rating
< 1	< 0.1	1
1 - 3	0.1 - 0.5	0.5
3 - 6	0.5 - 1.5	0.1
6 - 9	1.5 - 2	0.05
>9	>2	0.01

Additional Notes



Rockfall Appraisal and Risk Assessment Sheet
(*Continued over)*

Site Name : Hypothetical Quarry
Date : 10/01/2004

STRENGTH (material strength)

Field Definition	Compressive Strength(MPa)	Rating	Example
Rocks ring on hammer blows	> 250	15	Basalt, Derbyshire (321MPa)
Core chipped only by heavy hammer blows	100 - 250	12	Andesite, Somerset (204MPa) Carboniferous Limestone Buxton (106MPa)
Broken by heavy hammer blows	50 - 100	7	Magnesian Limestone, Anston (54MPa) *
Broken by light hammer blows	25 - 50	4	Middle Chalk, Hillington (27.2MPa)*
Thin slabs/edges broken by heavy hand	5-25	2	Bath Chalk, Corsham (15.6MPa)*
Can be crumbled by heavy hand pressure	1-5	1	Upper Chalk, Northfleet (5.5MPa)*
Crumbles easily in hand	<1	0	Folkestone Beds Sand, Reigate

* Dry samples

Bench	1	2	3	4	5	6
Strength	7	7	7			

+

RQD + Js + Jc + GW (Rock mass condition)

Parameter	Range of Values				
Rating	20	17	13	8	3
Spacing of discontinuities	>2m	0.6-2m	200-600mm	60-200mm	<60mm
Condition of discontinuities	Very rough surfaces Not continuous No separation Unweathered rock	Slightly rough surfaces Separation<1mm Slightly weathered	Slightly rough surfaces Separation<1mm Highly weathered walls	Slickensided surfaces or Gouge<5mm thick or Separation 1-5mm Continuous	Soft gouge>5mm thick or Separation<5mm Continuous
Rating	30	25	20	10	0
Ground water	Completely dry	Damp	Wet	Dripping	Flowing
Rating	15	10	7	4	0

Bench	1	2	3	4	5	6
RQD	8	13	13			
Spacing of discontinuities	8	10	10			
Condition of discontinuities	20	25	25			
Ground water	15	15	15			

+

JOINT ORIENTATION

General Description	Apparent Dip	Tabular	Blocky	Columnar
Very favourable	<0	0	0	-5
Favourable	<5	0	-5	-25
Fair	5-10	-5	-25	-50
Unfavourable	10-40	-25	-50	-60
Very unfavourable	>40	-50	-60	-60

Note: Local development of adversely oriented foreset bedding

Bench	1	2	3	4	5	6
Joint orientation	-25	-25	-25			
Total	**33**	**45**	**45**			
100 -	**67**	**55**	**55**			

x

WORKMANSHIP

Workmanship	Rating
Sawn / scaled using hydraulic breaker	1
Excavated/dug/natural discontinuity	2
Pre split/low explosive	3
Smooth wall	4
High explosive-some scaling	5
High explosive-average face	6
High explosive-irregular face	7
Crest damage-weathering or blasting / *localised overhangs*	0-3

Note if variable between

a	6
b	2

Bench	1	2	3	4	5	6
a + b	8	8	8			

x

SLOPE HEIGHT(H) ÷ 2

Bench	1	2	3	4	5	6
h	6m	15m	20m			
h/2	**3**	**7.5**	**10**			

x

GRADIENT RATING

Slope angle	Description	Rating
>80	Free fall	1
70-80	Bouncing	2
55-70	Bouncing	3
45-55	Bouncing	2
<45	Rolling	1

Bench	1	2	3	4	5	6
Gradient rating	3	3	3			
ROCKFALL HAZARD APPRAISAL	4,824 SM	9,900 SM	13,200 SH			
ROCKFALL RISK ASSESSMENT	482 SM	990 SM	1,320 SH			

ROCKFALL HAZARD APPRAISAL	
100 - 1,000	Significant-low
1,000-10,000	Significant-medium
>10,000	Significant-high

x

RISK RATING		
Exposure period for 1 hour		Rating
Day	10	0.1
Weekly	50	0.02
Monthly	200	0.005
Annual	2500	0.0004

=

ROCKFALL RISK ASSESSMENT	
< 10	Not Significant
10 - 100	Significant-low
100 - 1,000	Significant-medium
> 1,000	Significant-high

(Continued)

Benching Arrangements

Rockhead bench provision : Not Present

Nature of overburden slope: Minimal Overburden

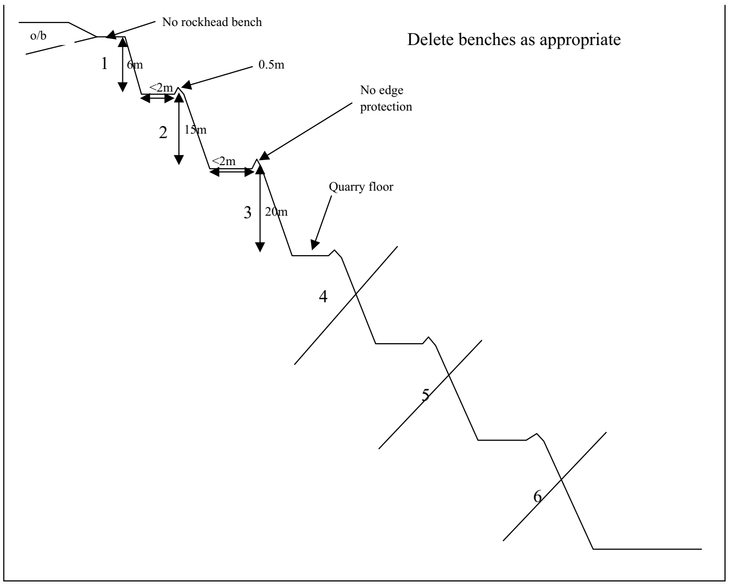
Bench No. :	1	2	3	4	5	6
Bench Width :	2	2				
Individual face angle :	65	65	65			
Edge protection height :	0.5	0				
Condition of bench (clean /choked /overtopping etc.)	**Choked**	**Choked**				

Rockfall cascade potential

	1	2	3	4	5	6
Hazard rating (individual bench) (i)						
x						
Bench width rating						
x						
Edge protection height rating						
Cascade rockfall hazard rating						
Cumulative cascade hazard rating **(ii)**		(1) 1,206	(1+2) 6,156	(1+2+3)	(1+2+3+4)	(1+2+3+4+5)
Cumulative overall rockfall risk rating **(i) + (ii)**						
OVERALL ROCKFALL RISK ASSESSMENT	**SM**	**SH**	**SH**			

Bench Width (m)	Bund Height (m)	Rating
< 1	< 0.1	1
1 - 3	0.1 - 0.5	0.5
3 - 6	0.5 - 1.5	0.1
6 - 9	1.5 - 2	0.05
>9	>2	0.01

Additional Notes



Generally

These *proformas* cover the collection of field survey data.

Field Survey

Fieldwork involves two surveys, one addresses the site in context whilst the other deals with site specifics. Both surveys are cross referenced to a photographic record.

- Site in Context

  This survey combines objective and subjective data common to landscape assessment. Restored quarry faces/slopes are considered against the broader landscape context. The survey includes an assessment of predicted change over time. Local landscape elements, features and vegetation relevant to quarry slope restoration design are identified to assist with future analysis and recommendations.

- Site Specific

  The site specific landscape survey complements the geotechnical survey. Included is a record of the visual characteristics of the various rock types and how these vary over time, details of the restoration techniques used and the degree of conformity with the broader landscape context. Types of growing medium used are recorded as well as vegetation establishment, success rates and conformity with context.

Analysis

Analysis of field survey data falls into two distinct stages. The aim of this process is to rank each site with a score based on its overall net contribution to the landscape (Stage 1) thereby providing the basis for an examination of the success or failure of restoration techniques (Stage 2).

FIELD SURVEY ANALYSIS

STAGE 1 – SITE RANKING

SITE		RECORD												SITE RANKING[1]					
		1		2		3		4/A		4/B		4/C							
		Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	0	1	2	3	4	5
1.																			
2.																			
3.																			
4.																			
5.																			
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37.																			
38.																			
39.																			
40.																			
41.																			
42.																			
43.																			
44.																			
45.																			

1. Site Ranking based on net contribution to the landscape.

0 = Negative short and long term.
1 = Negative short term, neutral long term.
2 = Negative short term, positive long term.
3 = Neutral short term, neutral long term.
4 = Neutral short term, positive long term.
5 = Positive short and long term.

FIELD SURVEY RECORD A

VISUAL QUALITY ASSESSMENT : SITE IN CONTEXT

SITE:	DATE:	
1. DO THE QUARRY FACES/SLOPES DRAW THE EYE? EXPLAIN. Include reference to distance, scale, colour, texture, skyline, landform and landcover characteristics as appropriate, cross reference to photographic record.	YES	NO
2. DO QUARRY FACES/SLOPES DETRACT? EXPLAIN. Include reference to the sites relationship with its surroundings, associations and landscape value.	YES	NO
3. DO QUARRY FACES/SLOPES MEET VISUAL QUALITY OBJECTIVES?[1] EXPLAIN. Include reference to the replication of more natural appearing topographic features and vegetation or to the insertion of new interesting and/or attractive features into the landscape.	YES	NO

[1] Visual Quality Objectives. To mitigate visual intrusion or even contribute positively to the broader landscape restored quarry faces/slopes need to achieve certain visual quality objectives. These are:
1. the successful replication of more natural appearing landscape elements or features in context and/or;
2. the creation of new landscape elements or features which contribute positively to the scene and which may also add to the way in which the landscape is valued i.e. add visual/historic/ecological/recreational interest.

4. WHAT IS THE LONG TERM PREDICTION FOR THE QUARRY FACES/SLOPES? DESCRIBE. Include reference to natural processes, timescale, changes in colour, landform and landcover. Consider effects against items 1-3. Significant effects in respect of items 1-3:				
A. Will the quarry faces/slopes draw the eye?	YES		NO	
Explain				
B. Will the quarry faces/slopes detract?	YES		NO	
Explain				
C. Will the quarry faces/slopes meet visual quality objectives in the long term?	YES		NO	
Explain				

5.
IDENTIFY LOCAL LANDSCAPE ELEMENTS AND FEATURES THAT ARE RELEVANT TO QUARRY RESTORATION DESIGN
Include elements with landform/landcover replication potential. Cross reference to photographic record.

Item	Description	Photo Ref	Element	Feature	Replication Potential	
					Yes	No
1.						

6.
IDENTIFY LOCAL PLANT SPECIES THAT ARE RELEVANT TO QUARRY RESTORATION DESIGN.

Item	Species	Comment
A.	WOODLAND	
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
B.	HEDGES	
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
C.	OTHER (Scrub, Shrubs, Grassland etc)	
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

FIELD SURVEY RECORD B

VISUAL QUALITY ASSESSMENT : SITE SPECIFIC

SITE: DATE:

1. ROCK TYPE(S)

Item	Rock Type	Visual Characteristics

2. RESTORATION TECHNIQUE(S)

Item	Technique	How long established (years)	Conformity with Context				
			Total	Major	Medium	Minor	None

3. GROWING MEDIUM. Describe, uppermost material first followed by underlying strata in sequence.

Item	Type	Typical Thickness (m)	Comment

4. VEGETATION ESTABLISHMENT. Cross reference to Restoration Techniques.									
Technique Ref	Type/Species	Success Rate			Conformity with Context				
		High	Medium	Low	Total	Major	Medium	Minor	None

5. NOTES

Below is a brief checklist in approximate chronological order for the planning, design, modification and management of final slopes. It includes many of the steps that are routinely required in any mineral planning and development procedure. It is followed by a note identifying where an SME will have to, or may have to seek outside advice to comply with the law or to avoid operating problems. These are grouped into mandatory assistance, recommended assistance and possible assistance.

General data collection and information retrieval

- PPGs, MPGs, Structure Plan, Local Plan, Mineral Plan
- Ordnance Survey Plans, British Geological Survey Plans, and Soil Survey Plans
- Planning Permissions, Section 106 Agreements, legal obligations, reviews of planning conditions
- Land ownership and control
- Previous environmental impact assessments

Site data collection and investigations

- Topographical survey extending beyond quarry limits
- Geological and geotechnical investigations
- Hydrological and hydrogeological investigations
- Investigations of top and subsoils
- Flora and fauna survey
- Local vegetation/land cover survey
- Land use arrangements
- Local landforms/geomorphology

Consultations

- MPAs
- Local Authorities including County, District, Borough and Parish Councils
- English Nature
- English Heritage
- The Environment Agency
- Utilities
- Local interest groups

Assessments and analyses

- Determination of volumes of minerals and volumes and types of potential waste materials
- Determination of potential working areas within environmentally and economically viable working limits
- Viable working time scales and alternative working methods
- Landscape and visual context, landform restoration objectives
- Potential after-uses
- Access alternatives

Specific slope design

- Design of final quarry void
- Determination of direction of working
- Detailing of quarry design including geotechnical design

- Specification of face geometry including overall heights, bench heights and widths *etc*.
- Identification of buttressing requirements and volumes of fill required

Phasing

- Establish phase restoration sequence
- Schedule materials handling and safe working procedures

Operations and restoration

- Implement excavation/materials handling
- Implement planting plan
- Attend to SSSI and RIGS access arrangements *etc*.
- Complete all necessary safety barriers, fences *etc*. to control access

After-use/maintenance

- Complete final stability assessment
- Establish maintenance inspection regime
- Monitor public access as required

Where advice may be required

This part of the checklist sets out items with which an SME aggregates company may require assistance. Such assistance might be at the initial planning stages or when the design of final slopes is in progress. It could equally be when the slopes are being excavated or modified or during the completion of the restoration and maintenance works. The type of assistance can range from mandatory involvement where meetings are required or independent studies have to be produced and/or where the services of outside professionals are necessary. This can arise since such skills are rarely found in-house in SMEs. Other situations arise where it is strongly recommended but not mandatory that such advice is received. Finally there are a number of elements in the activities surrounding the investigations, design, construction, operation and completion of final quarry slope excavations and associated works where the SME may find it helpful to have advice.

Mandatory assistance

At the planning stage it is likely that Environmental Impact Assessments (EIA) will be required for all but the smallest of quarry operations. The reporting for such assessments may cover any of a large number of environmental impacts and will be specified by the MPA if not previously agreed in meetings held between the parties to assess the impact scoping requirements. At that stage specialist reports are required to support the planning application. These may range from noise and dust to archaeology. Those relevant to final slopes are most likely to relate to stability (especially where SSSIs or outside properties may be adversely affected) and to landscape and reclamation matters. It is most unlikely that MPAs would consider an EIA to be adequate if the supporting statement on a matter relevant to stability or landscape had not been produced by a competent professional if such work had been specified in the impact scoping exercise. It should be noted that many MPAs use other professionals to check the veracity of reports in EIAs.

At the design stage there are further mandatory exercises that may be necessary relating to final slopes. Although the EIA exercise may have itself produced a competent slope and reclamation design, further reporting may well be required if the proposed slopes might be designated as comprising a significant hazard under the Quarries Regulations 1999. Legally all slopes have to be designed (Regulation 30) and specific reporting by a geotechnical specialist (defined in the Regulations) is required of all significant hazards comprising excavations and tips (Regulation 32 and ACoP). The appraisal of whether or not a specific slope is a significant hazard (*i.e.* the hazard appraisal) is mandatory but should be capable of completion in-house. That record of the appraisal must be kept by the operator. A geotechnical assessment where required, must be undertaken in the manner set out in Regulation 33 and Schedule 1. (It is also mandatory for the operator to notify the HSE of any significant hazards in proposed excavations giving not less than 30 days notice of the intention to construct the excavation).

If as part of the restoration works or for any other reason the final slope needs to be modified that modification also needs to have a design and appropriate geotechnical reporting to check the new design if it constitutes a significant hazard.

Recommended assistance

Unless the SME has in-house personnel with specific surveying and geological skills, it is strongly recommended that assistance is obtained when large volumes of spoil are an integral part of an intended programme of final slope restoration. It is important that the balance of overburden and waste materials to mineral and that the volume of wastes that may be available for final slope buttressing and general restoration are clearly understood. As noted in Chapter 4 this is a frequent area of miscalculation or neglect in some SME quarries.

Similarly the development of phasing plans and proper cross sections of the quarry at different stages of working and completion of the final slopes are highly desirable. This allows the calculation of the waste required for buttressing *etc*. and also the availability of storage of waste and confirmation of where waste will finally reside. Those with experience and skills in geological, geotechnical and operational aspects of quarry development are best suited to this form of work. Experience suggests that this is most likely to be required where there is thick overburden, deep weathering of bedrock, interbedding of waste materials and especially inclined and potentially unstable bedded aggregate minerals.

Where relevant, SMEs may find it valuable to engage professionals to create three-dimensional models of a quarry (or part of a quarry) and have these integrated into a computer model of the surrounding landform. This allows alternative slope solutions to be tested for their visual impact and contribution to the overall landform / landscape restoration.

Possible assistance

SMEs sometimes require advice in establishing landform replication objectives within the context of optimising mineral recovery.

SMEs may also require advice on safe working practices in matters such as face scaling or whether it is necessary to redesign a final slope.

Assistance is sometimes found to be helpful with respect to advice on soil investigation and planting schedules and techniques.

ACoP	Approved Code of Practice
Backfill	The placement of quarry waste on a quarry floor
Bench	A horizontal step in a quarry face used for access, stability or rockfall protection
Bund	A mound or pile of placed material typically to act as a rockfall trap
Burden	Material between the quarry face and the blast hole
Breakback	The collapse of the upper section of a bench following blasting.
Buttress	Support provided to a quarry face by fill material or in limestone valleys a protruding outcrop of rock in front of the headwall.
Crest	The upper edge of an excavation or bench
Doublehandling	The repeated movement of waste materials
Edge Protection	A bund or other solid barrier to prevent vehicles and persons accidentally falling over the crest of a slope or bench
Footwall	The face or floor of a quarry that is parallel to bedding surfaces
Geotechnical Domain	The area around a quarry with similar geotechnical features including similar directions of inclination of bedding, jointing and face alignment
Hazard	A feature having potential for harm
Headwall	In limestone valleys a continuous line of rock outcrop commonly with scree at its base and occasional buttresses of rock in front of the feature
Highwall	The down-dip face of a quarry excavation
HSE	Health and Safety Executive
Hydroseeding (or Hydraulic seeding)	The method of applying seeds, fertiliser and adhesive to inaccessible or dangerous areas using high pressure sprays
Landform Replication	The production of quarry faces to simulate natural slopes in the surrounding countryside
Low Wall	The up-dip face of a quarry excavation where bedding is undercut

MIRO	Mineral Industry Research Organisation
MPA	Mineral Planning Authority
MPG	Mineral Planning Guidance
Notifiable Slopes	Slopes that comprise significant hazards of which the HSE must be notified
ODPM	Office of the Deputy Prime Minister
Overburden	Uneconomic mineral material above minerals typically comprising superficial deposits
PPG	Planning Policy Guidance
Pre-split Blasting	Blasting to minimise damage to a rock face formed in advance of excavation and production blasting
RIGS	Regionally Important Geological Site
Rock Mass	A body of rock that includes discontinuities such as bedding, jointing or faulting as well as intact material between discontinuities
Rock Traps	Devices including fences and bunds to prevent rockfall travelling beyond a prescribed distance from the toe of a rock face
Rockfall	The collapse of loose material from an excavated face often known as “falls of ground”
Rockhead	The level or surface at which bedrock is found beneath superficial materials
Scaling	The mechanical removal of loose rock from a quarry face
Scree	Debris naturally occurring from the collapse of small fragments of rock from an overlying face *e.g.* headwall
SME	Small and medium sized enterprises
SSSI	Site of Special Scientific Interest
Stabilisation	The support by artificial means of an excavated face including buttressing, rock bolting, netting *etc*.
Stemming	Frictional material placed above the explosive in a blast hole to concentrate the gasses and explosive stresses in the body of the rock
Subsoil	Weathered rock below the topsoil, which lies within the plant root

zone but does not contain large quantities of organic matter

Superficial deposits Loose or poorly cemented materials (clay, sands, gravels) that overlie bedrock materials

Toe The lower edge of a bench or quarry excavation

Topsoil The upper layer of soils enriched with organic matter

Waste Discarded or unused material excavated or from processing of minerals in a quarry

Prof. Geoffrey Walton is the senior partner in the Geoffrey Walton Practice established in 1973 and extensively involved in the design of quarries and the geotechnical engineering of excavated slopes and tips. He originally trained as a geologist, but holds a PhD in Mining Engineering from Nottingham University and is a visiting Professor of Mining at the University of Leeds. Previous publications include handbooks on the design of quarry slopes and tips and a review of restoration blasting. He is continuously involved in quarries both large and small and has been instrumental in extending the concept of landform replication.

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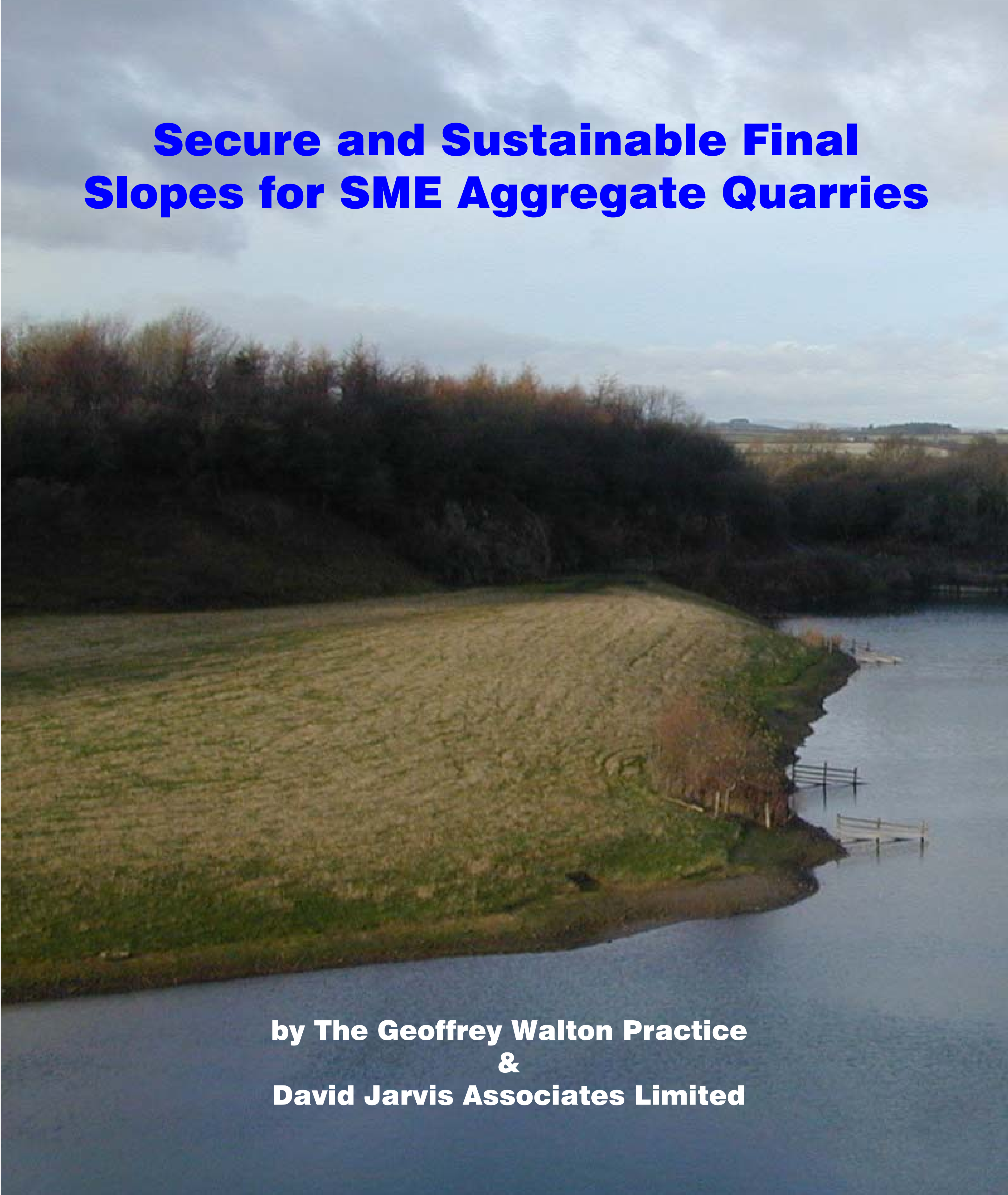

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by The Geoffrey Walton Practice
&
David Jarvis Associates Limited

ISBN 0897766882