PRINCIPLES OF DESIGN FOR HARD ROCK QUARRIES

4-3.1 INTRODUCTION

Quarrying in hard rock deposits usually requires different techniques to those employed in working generally unconsolidated sand and gravel deposits. Whilst many of the overall considerations are essentially similar (e.g. establishing a viable resource, determining the available area for development, assessing volumes of waste, overburden and other allowances, identifying the requirements for excavation, haulage and processing plant), there are several specific areas in which different assessment and design requirements are necessary.

For the purposes of this paper, hard rock quarries can basically be defined as those where it is not possible to excavate the quarry without some degree of primary fragmentation of the rock. This primary fragmentation is necessary to reduce the rock mass to a particle size that can be dug from a loose pile. It will be achieved by drilling and blasting in most circumstances, but depending on the degree of weathering and fracturing of the rock mass, it might be achieved by ‘ripping’ using a dozer or a combination of ripping and blasting.

Hard rock quarries normally include excavations in sedimentary, metamorphic and igneous rock types. In each rock type the general principles will be similar in the design of the quarry, the phasing and scheduling of operations and the restoration of the workings. There may be some differences in processing arrangements, but these are normally a function of the quality of the material being quarried and the required product specification. It is beyond the scope of this paper to consider such elements in detail, but some mention will be made of the basic requirements as they may influence design considerations.

Working hard rock quarries is generally a more complicated and intensive process than quarrying sand and gravel. Typically, costs will be higher since technological issues have a greater bearing on the methods of excavation and the types of plant that can be used. Often, one of the overriding concerns in the design process is the operating cost (a function of the quarry scheduling arrangements and plant selection).

It may be relatively straightforward to assess the costs of alternative plant selections (a simple spreadsheet model is often used) and to attempt to optimise based on fleet requirements. However, if the quarry designer is unfamiliar with the geological setting and its implications for pit layout and working arrangements these costs can prove wildly unrealistic. It is therefore critical that the quarry designer has a thorough understanding of the specific site conditions and sufficient skill and experience to assess the implications for design at a very early stage. The design of the pit may then lead to alternative plant selection which may be economically sub-optimal, but allows for a greater proportion of the reserve to be recovered, thereby maximising income. There will inevitably be a balance in this process; at some point it will become uneconomic to recover any further reserves irrespective of the plant selections.

Because of the investment required in opening and operating a hard-rock quarry, they generally would be expected to have a longer life than a sand and gravel quarry. As such initial resources will often need to be greater, even though production output may be similar to sand and gravel operations.

Relative to sand and gravel operations, hard-rock quarries normally have very little waste (in the form of overburden) and typically have low overburden stripping ratios. This can lead to problems in restoration. In addition, soil storage issues may be a problem; unlike sand and gravel operations there is often very little opportunity to progressively restore workings until the quarry is exhausted. Restoration plans, prepared at the time of quarry design, can also become unrealistic over the life of the site. Where this may be several decades, changes in legislation, acceptable quality of restoration or other factors can and do make such plans inappropriate at the time of their implementation. The quarry designer should therefore be as flexible as possible in preparing such elements. Conversely, the licensing authorities must recognise the potential difficulties or undesirability of implementing any scheme prepared at the start of a quarrying operation that may not be undertaken until 20 or 30 years after any permission was given. In this context, outline schemes of restoration that are subjected to periodic reviews and approvals to take account of changing circumstances are more appropriate for hard-rock sites and should be considered by all parties.
4-3.2 DEFINING THE SITE REQUIREMENTS

Hard rock quarries generally take one of two forms:

- Hill-side quarries – characterised by a general downward haulage of excavated material from the quarry area (up slope) to the processing plant (lower down the slope); or,
- Open-pit quarries – where quarrying workings are generally below the level of the processing plant and excavated material is hauled up and out of the pit.

Hill-side quarries may often become open-pit quarries once the level of excavation has reached, and subsequently extends below, the quarry plant area. Examples of each are shown in Plates 1 and 2.

The choice of whether a hill-side or open-pit operation is contemplated is usually dictated by the site topography, ownership boundaries, geological structure and environmental considerations (hill-side quarries can be very obvious features and have a high visual impact).

It is assumed that, for the purposes of this paper, a hard-rock resource has been identified and is considered suitable for quarrying subject to the usual economic, technological, environmental and legislative matters being satisfied. The following sections detail some of the key areas of concern to the quarry designer and highlight the effects that these may have in the preparation of designs.

Plate 1 – Hill side quarry
4-3.2.1 Initial scoping

Appendix 4-2, on the principles of design for sand and gravel deposits, draws attention to several key issues relating to the initial assessment of a proposed quarry site, which are summarised as:

- Confirmation of suitability of quality of quarried products for use;
- Initial estimates of resource quantities; and
- Assessment of potential development constraints.

These factors also affect the initial consideration of a hard-rock site and must be considered at the earliest stages of the design process to establish the potential viability of proceeding with designs.

Processing of material excavated from hard-rock quarries can alter its potential use (irrespective of the physical properties of the rock). Different methods of crushing can produce different shapes of material (which are typically applicable to different potential uses). The quarry designer will, at the initial stages therefore be involved in discussions with other departments within the quarrying company in determining the type of material required. This may affect decisions regarding the rate of working, the style of blasting, and the quantities of waste rock which arises.

Since geological properties (fractures, joints and bedding) may affect the breakage characteristics of the rock, it is essential that early consideration of the geotechnical properties of the rock mass be given. These may affect the type of breakage that would be expected during the quarrying operations and hence the products that may result.

4-3.2.2 Quantitative and qualitative assessments

A quantitative assessment of the volumes of material (overburden and rock) within a hard-rock site will be very similar for that undertaken for sand and gravel deposits. This requires a thorough consideration of all available site data (gathered from site investigations, topographic surveys, desk studies etc.) and the preparation of detailed geological models for the site.

Plans of the site should be prepared, together with structure contour plans for the rock to be quarried, isopachyte plans of the overburden and if appropriate a consideration of the ultimate floor level of the proposed pit. This may be determined by a consideration of:

- The level of any local water table;
- The quality of the rock to be worked;
- Planning restrictions; or,
A potential limit based on an initial assessment of the overall pit slopes.

From these basic plans, the potential recoverable resource may be assessed. Again, this may be achieved by computerised methods or by hand calculation. Whichever method is adopted, it is important that this is verified or double-checked by other methods. This may be as simple as calculating volumes based on average areas and thickness of material, using a scale rule placed on the plan. This can identify any ‘order of magnitude’ errors in the initial assessment – a common mistake that, if left unchecked, can have significant consequences subsequently.

Qualitative assessments in hard rock quarry designs address the physical appraisal of the material that may be produced when quarrying (which will typically consider the results of laboratory or other tests undertaken on samples recovered during site investigations). They must also, however, consider the geotechnical setting of the proposed quarry site. Data relevant to such assessments is usually gathered through consideration of the site investigation data (which will include detailed logging of core samples) and geological/geotechnical mapping and logging undertaken on any exposures in the area.

The first paper identified some of the important factors related to quarry design that depend on consideration of geotechnical data. These are essential in establishing the design rules that will be applicable to the preparation of the quarry design and phasing plans. Such design rules include:

- Minimum allowable bench widths (both final positions and working bench widths);
- Maximum allowable bench heights, and maximum overall slopes in all materials to be excavated;
- Maximum foundation slopes as well as maximum slope angles and heights for in pit and out of pit spoil (this may vary according to the type of material to be placed);
- Minimum allowable haul road widths, maximum allowable haul road gradients, circumference of bends and other aspects of mineral haulage in pit (e.g. maximum gradients for in pit conveyors and widths to be allowed for such structures).

The geotechnical data will identify differing geotechnical settings within the quarry area and will allow the quarry to be ‘zoned’ accordingly. The assessment should identify the likely slope failure modes in each zone and the design rules will be prepared to reflect each area as appropriate. This may result in varying bench and slope arrangements in different areas of the pit and each must be accommodated in the design.

Plate 3 shows well developed bedding in a hard rock site. The spacing and orientation of these discontinuities, and their dip, have influenced the development of the quarry benches.
The design rules may also influence such aspects as direction of working and identify face alignments to be avoided in particular settings. The direction of working can materially influence advancing face stability and will therefore be a prime consideration in the preparation of the quarry phasing plans.

The effects of weathering on rock masses can be significant and may materially affect their suitability for use as an aggregate. The quarry designer should always be alert to the presence of weathered material in the deposit since it may influence not only the acceptability of the quarried product for sale but may represent zones where stability issues can become problematic.

Weathering can be relatively shallow (where there is significant overburden cover) or can extend to some depth in the rock mass. Depending on the degree of weathering, some or all of the weathered material at or near surface may in fact represent additional overburden and its volume should be calculated in determining the extent of the resources.

Deeper weathering may also have occurred along faults, bedding planes or other discontinuities in the rock mass and these may be identified in the SI data. The presence of such material, if unacceptable as aggregate, may reduce the available resource further.

In some circumstances however, mild weathering may actually improve the rock mass when considered as a body for quarrying. The opening of joints, etc within the rock may lead to easier digging, with reduced need for explosives and the potential to undertake some primary fragmentation by ripping. Structurally however, this weathering may result in less stable slopes, since the rock mass is more heavily broken to begin with.

4-3.2.3 Losses and allowances

There are a number of factors that will limit the potentially recoverable resources identified in the initial stages of appraisal. As for sand and gravel operations, it is crucial to make considered allowances and assumptions at an early stage of the design process to adequately account for any losses. This is necessary to properly reflect the total quantity of rock that may be sold as product and to allow sufficient space for the tipping of wastes as they arise.

Too often quarries can become quickly ‘muck-bound’ due to an underestimation of the quantities of waste to be produced at various stages in the operation. In a hard-rock quarry, waste may arise from the following sources:

- Soil and overburden;
- Interface materials (weathered bedrock) at the top of the deposit;
- Unusable interbedded materials within the body of the deposit;
- Broken/weathered rock in and around faults in the deposit; and
- Wastes produced at the processing plant, including dust-sized material, and ‘scalpings’ – either over- or undersized material removed prior to processing.

Some of these quantities may be calculated as part of the design process (e.g. the soil and overburden volumes can be assessed and the presence of any interface or interbedded material can be determined from SI data). Others allowances may be simple assumptions (e.g. a stand-off around faults based on a review of the nature of the faulting or observation of exposed faults in the locality, the anticipated volumes of processing waste based on discussions with plant manufacturers or through operational experience, etc.).

Based on the measurable quantities of waste and the allowances assumed for unknowns, the requirements for waste disposal areas can be determined and accommodated in the designs. It may be necessary to arrange for both out-of-pit and in-pit spoil disposal and this will need to be addressed in the preparation of the quarry phasing to ensure that sufficient capacity for waste disposal is available at the appropriate stage of development.

It is usual in the initial stages of design to prepare a conceptual pit on the basis of overall slope angles (i.e. incorporating bench height and bench width), determined by the geotechnical assessment. This will often exclude any ramps, etc necessary for haulage however. Such items often cannot be properly assessed until later in the design process when plant and equipment selection is more advanced and some consideration has been given to the phasing of such workings. In such circumstances, allowances (in the form of percentage reductions in quarry yield) are normally made. Such allowances generally affect only the quantity of rock to be produced and do not materially affect the calculation of waste quantities.
4-3.2.4 Initial infrastructure/development issues

Site infrastructure for hard rock quarries is generally larger and more permanent than that for sand and gravel deposits. There are also a range of other issues that affect its selection and siting (considered further in Section 3.4 below).

As for sand and gravel workings there are several items that will be common to all hard-rock workings and should be addressed early in the design process:

- Access to the site;
- Location of plant and any associated facilities;
- Access to the plant area within the site;
- Location of water management features;
- General site screening and security; and
- Soil, overburden and waste stockpiling.

The location and sizing of such features should always be carefully considered to avoid sterilisation of potentially workable reserves. Since hard-rock quarries are commonly highly visible features in the local landscape, screening at the site boundaries will be a significant matter. Screening banks constructed may be for visual amenity, but may also serve as noise baffles around sensitive locations.

The screening banks formed (commonly from soil and overburden) may represent part of the final restoration plan for the site and as such should be carefully considered in the early designs. It may not be possible to gain access to areas of the site as the quarry develops and the opportunity to re-handle such materials in the future may not exist.

4-3.3 DESIGN CONSIDERATIONS

For hard-rock workings, there are four principal stages in the extraction process:

- Soil and overburden removal;
- Primary (and secondary) fragmentation of the rock mass;
- Excavation and loading; and,
- Haulage to the processing plant.

Each should be considered as a continuation of the other in the process. Changes in proposals for one element may have consequences for the others. Many of the options will be dictated by site circumstances (e.g. site layout, topography, strength of the overburden and rock mass, plant selection, etc.) and as such there may be little flexibility in accommodating changes. Where practicable however the quarry designer will need to optimise the activities to arrive at an economically and environmentally acceptable solution.

4-3.3.1 Soil and Overburden removal

For hard-rock quarry sites, overburden may range from practically nothing (in areas of high relief) or to many tens of metres (in low lying areas or faulted ground). The thickness of overburden above a hard rock deposit can vary significantly across a site, depending on the surface topography and the nature of the underlying interface. Some typical settings are shown in Figure 1.
Figure 1 – Examples of overburden and weathering cover

Appendix 4-2 on sand and gravel deposits discussed the basic concepts of soil and soil handling in the context of mineral operations and it is not proposed to repeat this here. Suffice to say that, in areas where there is an appreciable soil cover, good handling techniques must be adopted to conserve as much of the soil as possible, and to retain it in a condition suitable for re-use.

Overburden in hard-rock settings may comprise a loose, unconsolidated material (clay, broken rock, gravel, etc.) which can be readily excavated using appropriate plant. The removal of the material away from the quarry area is normally a pre-requisite to avoid potential sterilisation of reserves. There is little potential for its removal and casting aside to storage using a single machine (e.g. a dragline, as might be used in a sand and gravel deposit) and typically removal of overburden requires separate digging and haulage plant.

Although a variety of excavators and trucks can normally be selected for such duties, it is normal practice to employ the plant to be used for digging and hauling the payrock from the quarry. This allows flexibility in duties, but may not be achievable economically, particularly where overburden is thick and rock production rates are high (requiring the overburden removal and quarrying activities to be undertaken as separate activities).

In some settings, the overburden can be highly indurated and requires drilling and blasting to break it prior to excavation. In such circumstances, the overburden removal is essentially the same as quarrying for payrock, and may be effectively undertaken by the same processes and plant. The broken overburden will be dug and hauled to the tipping area, rather than the processing plant.

Some overburden may be weakly cemented or thinly laminated and whilst it cannot be easily dug out, does not require drilling and blasting to break it. Ripping using a dozer with a rear mounted tooth (or tine) can effectively break the material, allowing the dozer to push it into piles that can then be dug and loaded for transport to tip.

As noted in the previous section, a common feature in humid tropical environments is a significant zone of weathering in the bedrock. In the absence of overburden (or where overburden is relatively thin), the weathered rock may be dug and tipped as waste (effectively overburden). It may be necessary to remove large quantities before acceptable payrock is exposed, and indeed in some tropical zones, there can be as much as a 1:1 ratio between the amount of weathered material and acceptable payrock on any particular site.
If the depth of overburden is significant, it may be necessary to have benched slopes in this material. Bench profiles will depend on the quality of the overburden and should be considered in the same way as quarry benches to ensure slopes remain stable and secure in the long term.

Disposal of the overburden to suitable screening banks or other areas will require careful planning and design. Given the potential long-term nature and size of such structures, there may be significant safety issues to be considered. The quarry designer will also need to prepare proper designs of tips and tipping rules should be established that will cover their construction, inspection and maintenance. This will take account of the geotechnical properties of the spoil and the physical setting in which tipping will occur.

Tips must be designed so that they are inherently stable. For this to be achieved they must have good drainage; this typically requires drainage measures to be incorporated as part of the tip design. Many major accidents and incidents at operating quarries have resulted from failures in tipped materials. Where tips may be close to the crest of an active quarry this may be of even greater concern since there is a very real potential for serious injury or fatality to any persons working on the quarry benches below. Tip design is considered in more detail in a subsequent paper.

It is good practice to leave a rockhead bench exposed at the interface with the payrock. The width of this bench will depend on a number of factors, but should ideally be wide enough to allow access to all areas of the quarry crest and accommodate suitable drainage measures to prevent flows into the quarry.

4-3.3.2 Mineral recovery

Hard-rock quarry workings may be wet or dry, depending on the depth to water table. It is not common practice to allow pits to flood during operation, and pumping may be necessary if water collects within the pit during working. This may require the formation of profiled floors and sumps to collect water prior to pumping. The precise arrangements will reflect the rate of inflow (normally a function of the porosity and permeability, mainly through joints and fissures, of the rock mass).

Most hard rock quarries (unless working in very thin rock units and achieving no significant depth) will be benched. Maximum bench heights, bench widths and face angles will be determined principally by geotechnical factors. However, operational constraints (reach of excavators, capabilities of drill rigs, quarry geometry) may dictate other arrangements that are less than those which may acceptable based on a geotechnical assessment. Similarly, there may be environmental factors that dictate bench geometry (e.g. the use of bench alignment and height to screen mobile plant to control noise, blast vibrations and dust, or for visual or landscape reasons). It must also be remembered that different arrangements may be required in different parts of any quarry to reflect a range of geotechnical zones or domains.

As noted in earlier sections, in undertaking any hard rock quarry design, it is essential to establish the design rules for the different areas of the quarry at an early stage. These will allow an early appraisal of the layout of the quarry, equipment selection and areas of concern to be addressed when developing phasing plans. Particular geotechnical settings may preclude development of benches in a certain orientation or may indicate areas where development should start when preparing each sinking cut for the lower levels.

Excavations of hard-rock quarries will generally require fragmentation of the rock to allow subsequent handling and digging. This is necessary to break the rock mass and produce a rock pile with lump sizes that can be handled by the excavation and haulage plant. The desired degree of fragmentation may be achieved in one or more cycles and these are considered further below.

Primary fragmentation

The major costs associated with hard rock quarrying are incurred in the loading from a rock pile and crushing of broken rock at the processing plant. Two basic techniques are commonly used in primary fragmentation:

- Drilling and blasting; and
- Mechanical breaking (ripping).

The selection of the method used will take account of:

- The degree of weathering of the rock mass;
The nature and frequency of discontinuities in the rock mass (fractures, joints, faults, bedding, etc.);
• The crystallinity, nature and grain size of the rock mass; and
• The impact strength of the rock mass.

The degree of primary fragmentation required is normally geared to producing acceptable sizes for loading and crushing. Primary fragmentation should be designed therefore to optimise the distribution of particle sizes within the rock pile, compatible with the loading and crushing plant. The selection of methods and the degree of fragmentation to be achieved should therefore be assessed against the proposed plant and methods of digging for the operation.

Inappropriate particle size in the rock pile can reduce efficiency of the loading plant, resulting in slow cycle times and increased wear to buckets and teeth in the excavator. When oversize material is delivered to the crushing circuit at the processing plant, additional effort (and energy) is necessary to reduce the lump sizes in the primary crusher. If blocks that are too large are delivered, the system can be temporarily put out of action as the crusher becomes choked, leading to a loss of production. Increased wear on the crushing plates can also result.

Blasting

The degree of fragmentation achieved in the blasting cycle is dependent on a proper blast design. Each blast should be considered individually to minimise unwanted effects (over- or under-breakage of the rock, environmental problems and safety issues). Often the primary consideration in determining the size of each blast (i.e. the amount of rock to be broken on any one shot) is the suppression of adverse environmental impacts (vibration and noise). This, however, may be contrary to the quarry operator’s requirements and a compromise is often required. A typical quarry production blast is shown in Plate 4.

Blast design can be time consuming and expensive if considered for each and every blast in detail. Consequently, it is common practice to determine a set of rules for a typical blast in different zones of the quarry to satisfy the often contradictory requirements for production of broken rock and environmental protection. Individual blasts will still require assessment, however, and should be properly recorded.

The degree of fragmentation produced during blasting is determined by two principal factors:

• Explosive energy creating new fracture surfaces in the rock mass; and
• Exploitation of existing planes of weakness, such as joints, fractures, etc.

Other factors relating to the choice and amount of explosives used, the arrangement of blast holes and the sequencing of detonation will also have an effect. Variations in these aspects can also be used to limit adverse environmental effects or to improve the profile of the blast pile.
Ripping

Mechanical breakage is possible where the rock mass is already fractured extensively (usually by inherent planes of weakness in the rock). Ripping, using a dozer fitted with a tooth at the rear, is the most common method.

In most quarries and deposits, ripping techniques may be used only on a limited basis if at all (for example, in areas of poor ground). They can be effective in short duration excavations (e.g. for construction projects) or in preparation of upper benches in a quarry (where the ground may already be fairly broken by weathering).

Where applicable, ripping has major cost advantages over drilling and blasting and avoids many of the environmental impacts associated with blasting.

Secondary fragmentation

If the primary fragmentation is inefficient and may not produce a well graded rock pile suitable for immediate loading and crushing. Geological conditions or a need to limit the amount of explosives used (in mitigating environmental impacts) may locally produce block sizes that are too great to be handled and, in such circumstances, it is often necessary to undertake secondary fragmentation.

This can be achieved using explosives, but such methods are normally unacceptable on safety grounds as the blast can be uncontrolled and result in fly rock being generated. It also produces significant environmental impacts (mainly noise). Mechanical methods are generally favoured including

- The use of a steel drop ball; and
- The use of a pneumatic/hydraulic impact breaker (rock pecker).

Drop balls are popular, effective and relatively cheap, but suffer from being slow and therefore inefficient where high production rates are required. Safety is often an issue as hazards arising from flying rock pieces are often associated with the method.

Rock peckers have a number of advantages in secondary breaking applications. They are efficient machines and can be used to accurately reduce block sizes in the rock pile (see Plate 5). In addition, they can also be used in other duties in the quarry, principally in scaling faces (to push off large hanging blocks that may pose safety hazards).
Mineral loading

Once broken rock has been created in a pile (either a blast pile or pushed up by a dozer following ripping), the material is loaded to the selected haulage plant (see below). Excavation plant commonly used includes hydraulic face shovels, hydraulic back acting excavators and wheeled loading shovels. Each has advantages and disadvantages, and selection will depend on:

- Required production rate;
- Rock type;
- Geometry of quarry faces;
- Geometry of the rock pile;
- Grading of the rock pile; and
- The type of haulage plant to be used.

The quarry designer should consider the plant to be used and must carefully match its required performance with its abilities and compatibility with haulage plant. Sufficient operating space must be made available on any bench/quarry floor to allow the plant to operate safely and efficiently.

4-3.3.3 Mineral transport

As for sand and gravel operations, the basic haulage methods available within hard rock quarries include use of conveyors or dump trucks. Each has some advantages and disadvantages and design implications arising from their selection will be considered below.

Conveyors

Unlike sand and gravel deposits, where particle size distributions are usually relatively narrow, the broken rock produced within a hard rock quarry tends to have a wide range of particle sizes. This may preclude the use of conveyors as the primary transport method from the working face to the processing plant. Conveyors work best with a restricted range of sizes to allow the most economic sizing and speed of belts.

In addition, within hard rock quarries greater flexibility and access to working faces is normally required. Rock may be produced from several faces at any stage of the operation, and while it may be possible for trucks to haul to a central conveyor, it is normal practice for the excavation plant to load directly to a conveyor feed hopper to minimise costs. Conveyors therefore offer relatively little flexibility, particularly where working space is restricted and the conveyor requires frequent relocation.
Some of these problems may be overcome if the primary crusher (either semi-mobile or mobile) is located in
the pit area. Under such circumstances the excavator could load directly to the crusher. A more closely sized
product could then be fed to a conveyor and transported to a more remote processing plant elsewhere on the
quarry site. Alternatively, the excavator could load to a truck for a short haul to the crusher station, prior to
removal of material by conveyor. This would reduce the cycle time for dump trucks and could reduce the fleet
required. The cost savings would then be used in providing a conveyor system. Again, however, this requires
some permanence in establishing the conveyor route and may only be feasible for more developed sites with
long haul distances. Unless sufficient reserves remain to justify the investment, it may not be economic to do
this.

Conveyors may be a consideration in some quarries where space limitations may preclude establishing full
width haul routes. Conveyors can typically operate at gradients of up to c 1:3 (vertical to horizontal) and hence
can be used to raise the broken rock over considerably shorter distances than may be possible by hauling
along roads (see below). New generations of high angle conveyors are now in use, which can be used at even
steeper gradients. Capital costs are high however and careful consideration in the context of the overall
economics of the operation will be a prime factor in their selection.

Dumptruck haulage

In most hard rock quarries, dumptrucks are the preferred method of haulage. Trucks may be either rigid
bodied or articulated. The latter, which are ideally suited to smaller deposits with lower outputs or limited
space, are more appropriate where ground conditions are poor.

Haulage can be a significant cost area and significant expenditure is incurred on fuel, tyres, engine/gearbox
maintenance and wear plates in the tipper body. For all but the latter, careful design of haul routes (and their
proper maintenance in operation) can help to minimise costs. Optimisation of fragmentation will play a part in
reducing wear to the tipper bodies.

There is a considerable amount written about the optimum gradient of haul roads (in limiting distance of haul,
breaking efficiency, engine efficiency, etc.). In general, gradients of 1:10 (vertical to horizontal) are usually
accepted as the most acceptable trade-off between economic, technical and safety concerns. Gradients can
be up to 1:8 over short distances if space or other considerations dictate.

Turns/corners on haul routes should be designed, wherever possible to be level, and all effort must be made to
avoid ‘turns-into-space’ (i.e. where the outside of a turn is at a crest of a slope). This is essential on safety
grounds and the quarry designer is best placed to ensure that such unsafe measures are avoided by careful
consideration of haul route and bench layout.

Haul routes into quarries can follow a spiral, or may be in the form of switchbacks on a single face. Both forms
of road have their advantages, but final selection of haul routing will be determined in the phasing of the quarry
workings; it is critical to ensure access remains to all levels of the quarry, even when working on higher
benches has been completed. Access may be required for maintenance work to benches, or to allow
subsequent restoration.

Where dumptrucks are used for haulage, care and maintenance of haul routes are key areas in ensuring that
efficiency is not compromised. Tyre wear and damage can be considerable if the running surfaces are allowed
to collect debris (from blasts or falling from trucks). Braking efficiency can be compromised if the surface is
covered with loose material and this can materially affect the safety of plant operators. Scrapers or sweepers
should be used regularly to clear running surfaces and to ensure ruts are avoided in loose materials.

**4-3.3.4 Siting of processing plant and quarry facilities**

The general principles for siting the processing plant and other quarry structures are generally as described for
sand and gravel deposits. However, it is not normally possible to locate the plant centrally to the area to be
worked, as this could leave the plant isolated on a ‘pillar’ of rock as workings proceed around it. Normally
processing plants in hard rock sites are located at the boundary of the working area and near the site access
where practicable.

Often, processing plants for hard rock quarries will be large and may be housed in relatively tall structures.
This presents problems when screening the site. Dust, noise and vibration (principally from crushers) are all
sources of potential nuisance and high environmental impact and the plant layout, location and screening
measures should be considered to minimise these problems.
It should be apparent that attempts need to be made to minimise the haul distances from the quarry to the processing plant. Whether the plant location is determined in advance of preparation of the phasing plans or vice versa, the quarry designer should always consider the location of haul routes to the pit-run stockpiles near the crusher circuit.

Sufficient space must be maintained to allow plant to operate and manoeuvre safely in such areas to prevent queuing and reductions in efficiency of the process. Where possible, haul routes to and from the working quarry should avoid crossing other roadways linking the quarry to the public road network. This minimises the amount of mud and dirt that may be dropped on surfaces used by road going vehicles and also provides for a safer environment. If at all possible, the quarry trucks and road going vehicles should be kept separate.

There has been a move in some countries to use of semi-mobile processing units within the quarry workings. These normally include primary crushers (which have already been mentioned in the context of haulage by conveyors), but increasingly include screening units and secondary crushers. This may be appropriate for smaller sites with restricted output, or in the early stages of quarry development in preparation for the installation of large fixed plant. Mobile units are also often used to supplement production from other plants when demand is high.

4-3.3.5 Site access

The site access should be located adjacent to a public road and should be properly screened and with suitable security to limit unauthorised access. As for all sites, consideration must be given to safe access and egress by laden trucks; the access should not be located where it would present a hazard to other road users.

4-3.3.6 Water management and lagoons

Site drainage measures will be required to protect local watercourses and to prevent uncontrolled run-off into the pit. Settlement and attenuation ponds may be required to clean the water prior to discharge. By appropriate design of slopes, channels and other features however, it is usually to limit the necessity for such ponds. This is a material consideration for hard rock sites in particular, where topography and space considerations often restrict the ability to form large ponds.

Pumping from the pit may be required where the workings extend below the water table or where high run-off into the pit causes standing water to accumulate. As noted earlier, it is common practice to form a sump in the lowest part of the workings as quarrying progresses from which water can be pumped to discharge.

Drainage measures may be required on benches to limit the collection of surface run off or precipitation. This may be achieved by cutting grips along the benches and channelling any run off to a suitable point to flow into the pit or for direct pumping. Alternatively bunds may be formed in certain areas to control flows.

4-3.3.7 Site restoration and after-use

Restoration of a hard rock quarry should include reclamation and rehabilitation of all areas disturbed by quarrying activities. This will include tipping areas, the quarry workings and plant areas.

For small sites, where quarrying may be completed over a relatively short period, it should be possible for the operator to define the nature of the restoration and after-use fairly precisely and to allow for this in quarry designs.

For larger sites, whilst the final restoration landform will always be defined as part of the quarry design, detailed planning of rehabilitation, reclamation and after-use may not always be possible. These operations tend to be longer in duration and it may be unrealistic (and indeed undesirable) to design the restoration scheme in detail at the outset of quarrying that may not be implemented for several decades. In such circumstances, the designs should more properly reflect the proper screening of the site and the rehabilitation of the boundaries and screens of the site at an early stage. This will then ‘hide’ the operations from persons outside of the site boundary. This screening and limited restoration at the boundaries may ultimately form part of the final restoration plan; with several decades in which to mature, it would be unreasonable to return and disturb such areas.

Typically, for deep deposits, restoration of the quarry workings may not be possible until the pit is ‘worked-out’. Access is often needed to large areas of the site, whether actively producing rock or not, depending on the benching and haul road layout. In such circumstances, no restoration will be possible until completion of the quarry workings.
Where deposits to be worked are relatively shallow (and are worked in lateral cuts), or where workings extend over larger, linear areas (i.e. working a ridge or similar topographic feature), some degree of progressive restoration may be possible (similar to sand and gravel operations). If quarry development takes place in discrete phases, restoration may be possible in one phase without affecting work in another.

Irrespective of the timing and nature of restoration, certain measures will always be required in the context of providing safe and secure slopes in the quarry. Intermediate benches may be designed for short term stability during operations. The stability may be compromised if they are to remain standing in the long term. As benches are formed in their final locations, further consideration may be required in assessing their design. This may require wider benches or flatter overall slopes to maintain either slope stability or to limit the effects of rockfall. Where practicable quarry operators should prepare the final benches for restoration as they are developing the pit. This particularly applies to higher benches that may be visible from outside the site and could otherwise remain unfinished for many years.

In some circumstances, it may be appropriate to return to worked out areas of the quarry and remove certain benches by blasting or other methods in an attempt to replicate natural landforms typical of the surrounding country. This has been achieved with varying degrees of success in various geological and geomorphological terrains in the UK. It relies on a thorough geomorphological survey and assessment in determining the nature of the final profiles and this should be considered when designing bench layouts.

Spoil may be re-handled and placed against some slopes to soften and flatten profiles, particularly when surplus wastes that cannot be accommodated in tips outside of the pit area. In such circumstances in-pit tipping would serve the dual function of disposal of waste material and restoration works.

In most circumstances there will never be sufficient waste generated at a site to backfill deep quarry workings. The nature of the workings and the geology may also render them unsuitable for landfilling (which would probably be uneconomic anyway since larger hard rock quarries tend to be sites way from centres of population).

Occasionally however, there may be an opportunity for filling if other quarries or industries open up in an area and need to dispose of waste materials. This can represent a good opportunity to backfill a site that could not be foreseen at the time of design and phasing. The adherence to a restoration plan prepared many years earlier can in such situations represent a missed opportunity to improve on such a plan. Operators and licensing bodies should always be aware of changing circumstances in relation to long-lived sites. Adoption of one restoration plan should not therefore prevent substitution of another at a later date.

There is a range of possible after uses of ‘dry-floor’ hard rock quarry workings. These include:

- Agriculture and forestry;
- Landfill;
- Industrial/built development;
- Nature conservation; and
- Geological interest.

For ‘wet-floor’ quarry workings (i.e. where pumping is required to depress groundwater during working and the pit will be partially or totally flooded once pumping ceases), restoration options may be more limited. As noted, it may not be possible to provide sufficient waste to backfill the quarry (even to a level above the local groundwater table) and a standing body of water will result. In such settings, it is unlikely that there will be much potential for any form of restoration other than nature conservation, or possibly limited public recreation (e.g. boating lake). Public use may not be viable though, due to remote location or access, security or safety problems.

### 4.3.4 SUMMARY OF BASIC DESIGN PRINCIPLES

The design of hard rock quarries is often a more complicated task than that for sand and gravel operations. All of the basic principles remain generally the same however.

Added difficulties arise in consideration of more complex geotechnical domains, typically higher capital and operating costs, extra environmental impacts and more complicated restoration requirements.

The quarry designer should attempt to reconcile each problem area before progressing designs too far. There should be regular reviews and discussions with other experts, particularly related to geotechnical issues and possible operational issues (including types of plant to be used). Restoration measures will be an area that
needs much attention. Agreements will need to be reached with licensing authorities regarding the general principles to be adopted, but mechanisms need to be included to allow for changes as circumstances arise on site.