SURFACE MINING METHODS

REFERENCE:


2.1 Ore reserves Suitable for Surface Mining

Ore reserves suitable for surface mining can be classified initially as;

- Relatively horizontal stratified reserves with a thin or thick covering of overburden
- Stratified vein-type deposits with an inclination steeper than the natural angle of repose of the material so that waste cannot be tipped inside the pit
- Massive deposits, deep and very large laterally such that dumping of the waste within the pit is not possible.

Of all the variations of surface mining methods available, the three most common methods only will be described here, namely;

- Strip mining
- Terrace mining
- Open-pit mining

Figure 2.1 refers to the classification of these methods
Figure 2.1  Classification of mining methods

Note how the general classification system works, from stratified (or layered) types of deposits, through the type of layering, the thickness of overburden and finally the means by which overburden is handled; specifically, in-pit or ex-pit systems.

A further consideration is the type of material (waste or ore) handling systems that can be used in each type of mining operation, namely cyclic (discontinuous) or continuous systems. Refer to Bullivant’s reference for a description and analysis of the two systems and how they could be applied (and under what circumstances) for each type of mining method considered here.
2.2 Strip Mining

Strip mining is ideally applied where the surface of the ground and the ore body itself are relatively horizontal and not too deep under the surface, and a wide area is available to be mined in a series of strips. Typical examples of this type of mining are the larger tonnage coal mining operations in Mpumulanga.

Favourable conditions are:

- Relatively thin overburden (0-50m maximum otherwise stripping ration and cost of stripping becomes too high)

- Regular and constant surface topography and coal layers (not more than 20º variation from horizontal on the coal seam – topography can vary more since pre-stripping can be used to level it – but this is expensive to apply)

- Extensive area of reserves (to give adequate life of mine (LOM) and to cover all capital loan repayments – typically more than 20 years life at 4-14mt per annum production)

Walking draglines are for many years the most popular machine for this type of mining due to their flexibility, utility and availability, but more importantly, their low operating costs for waste mining (R/t or R/BCM). The dragline is a typical combined cyclic excavator and material carrier since it both excavates material and dumps it without the use of trucks or conveyor belts. The dragline sits above the waste or overburden block, usually 50m or so wide, on the highwall side and excavates the material in front of itself, to dump it on the low-wall or spoil side of the strip to uncover the coal seam below it.

For maximum productivity, a long strip is required (over 2km in length) to reduce excessive “dead-heading” time. Longer pits increase the risks of time dependant slope failure in both the highwall and the (waste) low-wall and take up large surface areas that can cause rehabilitation and transport problems. If mixing of coal is important (to meet sales specifications) then long stripping lengths are also problematic in terms of the active mining fronts available for mixing the coal. Where highwall or low-wall stability is problematic, it becomes necessary to monitor the stability of the pit extensively. Where the floor dips in the direction of the highwall it is often necessary to improve the stability of the waste dump through the use of a variety of additional mining method variations, namely:

- Selective placing of the waste (soft, slippery material for example clay and shale) on top and not in the bottom of the waste dumps.
- Stripping or the blasting of the floor surface of the pit to give a better friction surface (especially if floor is a low-friction material – carbonaceous shale, etc.).

- Excavation of clay materials (typical shales) from the floor to expose material with more frictional resistance. That will normally require a bench extension working method together with the additional specialised handling of clay material (which will result in increased waste handlings costs and therefore reduced profitability).

Large scale floor slopes (ie. Coal seam inclinations) of more than 8 – 20º have in many cases lead to failures of waste dumps (usually coinciding with heavy rains, poor drainage and clay material in the bottom of the waste dump) and therefore modified terrace or even open-pit mining methods have to be applied – although these methods are often not financially viable with a low unit-cost high volume product such as coal. Note that small scale changes in floor (or coal seam) elevation or inclination are not as problematic from a geotechnical point of view, but nevertheless create extremely difficult working conditions when dragline mining is used (refer to Chapter 10 for details).

Nowadays, several large strip mines operate in areas that were previously mined by underground methods, for example New Vaal Colliery. In such cases it is difficult to anticipate the stability of the overburden and geotechnical surveys are required especially where underground rooms are required to be blasted (by collapsing the pillars between) prior to using a dragline on these areas. Irrespective of the precise geology of the coal seam, the general approach remains similar to conventional strip mining and Figure 2.2 and 2.3 show the terminology used and typical method of strip mining.
Figure 2.2  Strip mining terminology
2.3 Terrace Mining

Where the overburden is too thick (or the floor of the pit (ie. The ore inclination) is too steeply dipping) to allow waste dumping directly over the pit (as is the case with a dragline and strip mining), it is necessary to use intermediate cyclic or continuous transport (eg. trucks or conveyors) to transport the overburden to where it can be tipped back into the previously mined void.

It is a multi-benched sideways-moving method, the whole mine moves over the ore reserve from one end to the other, but not necessarily in a single bench. The number of benches used is usually a function of the excavation depth and type of machinery used (typically between 10-15m bench height and 1-32 benches in the terrace).

Examples of this type of mining are the German lignite mines (where bucket-wheel excavators are used to excavate the overburden – a typical example of a continuous excavating system) and, to a lesser extent, some coal mines in the UK. In these cases, trucks and shovels are used to work 10 benches simultaneously to expose the coal seams underneath. The uppermost layer of overburden is normally mined using hydraulic excavators and trucks, or (when soft material exists),
using a bucket wheel excavator, conveyor belt and stacker. These methods are more expensive to use than a dragline, but the dragline is itself not suited to this type of mining due to the limited dump radius of the machine and the much larger width of a terrace mine compared to a strip mine. It is possible however to use a dragline in combination with a "long" terrace as illustrated in Figure 2.4, but only in the lower or bottom benches where the dig and dump point are within the working radius of the dragline.

Figure 2.4 Combined terrace (pre-stripping of soft overburden) and strip mining (stripping deeper hard overburden) methods and associated equipment.

In South Africa, Grootegeluk Colliery is a typical example of terrace type of mining. Currently, 11 benches are mined, 6 of overburden waste and 5 of coal. A dragline cannot be used due to the depth of the coal and width of the pit, but later on in the life of the mine, the mined-out terraces will be back-filled with waste (ie. The mining method will change from modified terrace to conventional terrace – see Figure 2.1). On a smaller scale Mooiplaas Dolomite is also a terrace mining operation (in this case, ore is transported out of the mine using an in-pit crusher and conveyor and waste is tipped directly as envisaged in a terrace mining operation). Mine Figure 2.5 illustrates a typical 3 bench waste (OB1-3) and 3 coal seam terrace operation with mining moving from R to L in the diagram.

Where steeply dipping orebodies are encountered, the modified method is most often applied as shown in Figure 2.6 in a more typical 3 waste bench terrace operation with steeply dipping orebody. In this case, the pit dimensions are limited by seam exposure (pit length) and available working area (for mining and dumping faces) (pit width).
Figure 2.5  Typical terrace mining operation

Figure 2.6  Terrace mining method with around the pit conveyor and hydraulic excavator and haul trucks
2.4 Open-pit Mining

This is the traditional cone-shaped excavation (although it can be any shape, depending on the size and shape of the orebody) that is used when the ore body is typically pipe-shaped, vein-type, steeply dipping stratified or irregular. Although it is most often associated with metallic orebodies, eg. Palabora copper, Mamatwan and Sishen iron-ore, it can be used for any deposit that suits the geometry – most typically diamond pipes – Venetia, Koffiefontein and Finsch.

The excavation is normally by rope- or hydraulic shovels with trucks carrying both ore and waste. Drill and blast is most often used, which makes the process cyclic. Waste is dumped outside the mined-out area since no room is available within the pit. Waste is placed as close to the edge of the pit as possible, to minimise transport costs. Figure 2.7 illustrates the terminology used in the pit design and Figure 2.8 the mining method.

![Figure 2.7 Typical open-pit bench terminology](image)

Benches are normally excavated from 2-15m in height in stacks of 3 to 4, in between which is a crest on which the haul road is placed. When the number of benches in the stack increases, the road gradient increases too. Benches in the stack have a steep face angle whilst the stack and overall slope angles are flatter, thereby helping to prevent slope failures. From an analysis of overall slope geometry, it is clear that as steep a slope as possible should be mined, to reduce the overall stripping ratio. However, this rule is limited by the maximum gradient of the haul road – typically 8-10% which requires frequent wider crests, and the need to have flatter slope angles in places to provide slope
stability. Note that each pit slope can have a different angle according to the requirements of the design – with or without haul road, geology, etc.

Figure 2.8 Open-pit mining sequence (for pipe-like orebody)
Mineral and especially waste transport costs comprise the greatest amount of an open-pit mine’s working costs. To reduce this cost aspect – especially when the pit gets deeper, the following options are possible;

- In-pit crushers together with a conveyor belt, instead of truck transport. (a continuous transport system (conveyor belt) is usually much cheaper in terms of R/t hauled) and can be installed at a steeper angle thereby saving stripping costs by virtue of reduced stripping ratio.

- Trolley-assist on the main haul road. (electrical power supply to trucks) – faster trucks, steeper roads or cheaper R/t costs

- Computerised truck dispatch – more efficient use of trucks

- Steeper bench slope angles (in other words, a reduced stripping ratio) where stability allows them – especially at the bottom of the pit when LOM approaches end.

As a result of the high cost of rock transport – up to 50% of an open-pit’s total operating costs, many large pits consider continuous transport systems. The OPEC induced rise in the price of oil in the 1970’s and more recently in 2000/1 has forced mines to rethink strategies for reducing fuel consumption. Continuous transport systems (and the associated in-pit crusher if drill and blast is used) begin to out-perform truck based systems – since they are run on electricity, not diesel fuel. Whilst electricity can still be cheaply provided from local coal power stations (South Africa’s electricity is one of the cheapest in the world), considerable ore and waste transport cost savings can also be realised. These savings become all the more important as the depth of the pit increases, since the cost of transport increases exponentially with increasing vertical transport distance.

As a result of their application flexibility, truck and shovel systems are always popular and widely applied in mining, but in terms of energy-efficiency, trucks use only 40% of the energy input to move the load, the remaining 60% is used to move the tare mass of the truck itself. Conveyors use 80% of the energy input to move the load. Although oil prices are now at a more realistic level, energy costs of trucks are still 50% higher than that of conveyors in some parts of the world. In South Africa, with it’s low local production and small strategic reserve, together with the R/$ exchange rate, the trade-off between the two systems must be regularly re-evaluated. Chapter 9 contains more details concerning the design and use of continuous haulage systems.
EXAMPLE QUESTIONS

1 In surface mining, two excavation systems, namely cyclic and continuous, are defined;

1.1 Why are the two systems differentiated?

1.1.1 Illustrate the components of each system in terms of ground preparation, excavation, transport and dumping.

1.1.2 Under certain circumstances, components of both systems can be combined. What circumstances may lead to such combined systems being used?

2 Two surface mines are considering the use of a conveyor in conjunction with their current fleet of trucks and shovels. The mines are;

(i) a strip mine operation in which coal is transported out of the strip from a depth of 37m to a coal plant on surface, at a rate of 1,2mt per month.

(ii) an open-pit operation in which coal and waste are transported from a depth of 300m to either a waste dump or a processing plant on surface, at a rate of 1,22mt per month (ore) at a stripping ratio of 3:1.

Give advice to the mines concerning the practicality and utility of using a conveyor to either replace or supplement the existing systems.

Give advice to the mines as to what extra additional equipment they may need if they were to combine existing and new conveyor systems.

3 Explain the terms;

a. Loose cubic meters (LCM)
b. Bank cubic meters (BCM)

c. Bench, stack and overall slope angles and the factor governing the choice of slope angle in each case.
3. d. Overall (s)- and immediate (variable) stripping ratio (S'), with reference to the open pit mining method.

3.1 Illustrate a surface mining classification method that differentiates between strip- and terrace mining methods. Refer in your answer to a stratified ore body that lies relatively horizontal and include the other factors that would allow either method to be identified for a particular set of conditions.

3.2 With the help of diagrams, illustrate and discuss the differences between the two methods mentioned in 3.1 above, in terms of the mining process (especially overburden handling) and the typical dimensions of each type of mining. It is NOT necessary to discuss equipment choices.

4 Illustrate with a suitable diagram, how waste overburden and orebody geometry dictates the choice of mining method. You should consider four surface mining methods in your answer and show which methods may be combined and under what circumstances.

5 Explain the following terms with the aid of sketches, as they apply to an open-pit operation;
(a) Overall slope angle
(b) Bench stack slope angle

5.1 Why is the individual bench slope angle steeper than the stack slope angle, which is steeper than the overall pit slope angle?

5.2 Discuss the concept of stripping ratio and how haul road gradient, bench, stack and overall slope angles effect it.

6 What are the primary classifications of orebodies that are suitable for surface mining and on what basis would you decide if such an orebody can actually be mined?

7 What is meant by “break-even stripping ratio” and what factors would you consider when you need to determine its value?

7.1 Illustrate with suitable cross-section sketches showing ore and waste components, how overall stripping ration can be; a. constant
b. Increasing
c. Decreasing

over the life of an open-pit mine.

8 Describe, using suitable annotated sketches, the difference between terrace and modified terrace methods of surface mining. Give a typical example of a mine in South Africa that has used both methods and explain how the methods follow each other.

9 Describe briefly how the operational life of a mine (LOM) can influence the choice of transport equipment. Refer in your answer to a new open-pit mine and a deep open-pit mine that is near the end of its production lifetime.

STUDENT ASSIGNMENT

Compile your own notes from Bullivant’s reference paper, with particular reference to;

- The mining-method classification system
- Transport systems flow diagram (continuous and cyclic excavation and transport systems), component, combination and the degree to which they may be successfully applied and used in each type of mining method discussed.