Design of Mine Shafts

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Abstract

Many underground operations consist of several tunnels acting as accesses, haulages, production levels, and airways but there is only a limited number of shafts that can be developed for any given ore body and these shafts must be sunk in the right place with the correct configuration to get optimum operational benefit. Despite the extensive and widespread use of shafts as a primary means of access to the ore body for many mineral resources in South Africa, there is little current and comprehensive reference material which provides a central body of knowledge spanning the various design and cost factors involved in shaft design for either green field or brown field projects. The purpose of this paper is to cover some aspects which have to be considered when designing mine shafts. It is hoped that this paper will be used throughout industry as a quantitative basis for the comparison of various mine access options both for new and existing mines. This should form an integral part of any mine design process.

Key words: ore body, design, shaft, vertical, decline, and incline, cost.
**Design of Mine shafts**

**Introduction**

This is a short paper that aims to cover some aspects, which have to be considered when designing mine shafts. No attempt will be made to cover the design of hoisting systems or shaft steel work. The emphasis of the paper is on the South African mining industry.

Generally speaking, it is safe to assume that shafts are vertical or inclined openings sank into the earth’s crust in order to access mineral resources which are too deep to mine economically using open cut methods or adit systems. There are, of course, instances where shafts are sunk for purposes of storing radioactive material.

The mineral resource must be converted into a mineral reserve before one can start designing a mine shaft. This may sound very logical but, in the past, there has been situations where the shaft was sunk (on gut feel) first and the ore body found later with some pretty obvious economic consequences. An economically mineable reserve is therefore a pre-requisite for engineers to be able to start on the design process.

Since shafts play a major role in the general planning of mine development, their location is usually pre-determined. The location of a shaft can be changed when adverse geotechnical site conditions are encountered (K F Unrug, 1984).

The design of mine shaft is an iterative process, which requires several variables and options to be considered in order to arrive at an economic decision. The economic decision is arrived at by comparing the net present values (NPV) and internal rate of return (IRR) from the different options considered in the optimization process. The option with the most attractive financial option is then selected.

The design parameters mentioned above include, but are not necessarily limited to the following: depth of shaft, ore and waste tonnage to be handled, shift handling (work force), materials handling, mining machinery handling, ventilation requirements, capital costs, operating costs, and of course the selling price of the mineral commodity.
1.0 Purpose of a Shaft

Shafts are generally used for the following functions:

- To access an ore body
- To transport men and materials to and from underground workings
- For hoisting ore and waste from underground
- To serve as intake and return airways for the mine (ventilation)
- To provide a second egress as required by mining law
- Storage of nuclear waste

2.0 Shaft Cross Sections

2.1 Rectangular Shafts

Most shafts that were constructed in the 1900’s were of a rectangular cross-section because of the shape of the pieces of equipment that were taken down the shaft i.e. cages, skips, and counterweights were all square or rectangular in nature and so it made a lot of sense to sink or mine rectangular shafts. Breaking a square / rectangular shutter was however problematic and this slowed down the rate of sinking.

2.2 Circular Shafts

Almost all the hard rock mines now have circular shafts because the cross section provides good geometry for airflow and good rock support characteristics. The circular shutter is ease to move when doing concurrent lining resulting in faster work progress during sinking operations. This is an important aspect when it comes to the cash flow of the project.

2.2 Elliptical Shafts

Elliptical shafts were designed as an alternative to large circular shafts by simply adding half moons along the main axis. This had
the effect of reducing the circular excavation and therefore the cost of sinking the shaft.

3.0 Determining Shaft Size

As mentioned earlier the first step in determining the shaft size is to estimate the total reserves in the area to be exploited by the shaft. The reserve (ore body) size will govern the rate of mining and the mining rate will determine the tonnage (ore and waste) to be hoisted, the number of persons and material to be transported in a given shift. The foregoing is then used to determine the skip and cage sizes which in turn are used to calculate the total area required to accommodate these units. The shape and size of equipment to be taken down a shaft are also included in the calculation of the final shaft dimensions. The situation described here applies to rock, men, and materials shafts. This process is equally applicable to decline / incline shafts, the difference with the decline being trackless equipment and conveyors instead of the skips and cages. Inclined shafts also use monorails.

Determining the rate of mining can be summarized as follows:

- Identify possible mining layouts
- Define standard mining block (stope or panel size) per layout
- Calculate steady state conditions per level
- Define steady state inputs/outputs requirements per level
- Determine minimum access dimensions to cater for equipment and ventilation
- Calculate development requirements to get to steady state
- Simulate full level production from start of block to ore body extremity
- Determine the maximum number of levels that will operate simultaneously
- Estimate shaft size required to cater for sum of the requirements of the maximum number of working levels
- Do an economic analysis (NPV & IRR)
- Decide on optimum mining layout and shaft configuration

Determining the size of a ventilation shaft can be summed up as shown in Table 1 below.

<table>
<thead>
<tr>
<th>Description (Mine Opening)</th>
<th>Criteria (Air Velocities – m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downcast shaft</td>
<td>12</td>
</tr>
<tr>
<td>Upcast shaft</td>
<td>18</td>
</tr>
<tr>
<td>Intake airways</td>
<td>6</td>
</tr>
<tr>
<td>Return airways (no personnel)</td>
<td>12</td>
</tr>
<tr>
<td>Chairlifts</td>
<td>5</td>
</tr>
<tr>
<td>Conveyor declines</td>
<td>3</td>
</tr>
<tr>
<td>Diesel engine dilution factor</td>
<td>0.12 m³/s/kW</td>
</tr>
</tbody>
</table>

**Table 1: Ventilation Shaft design criteria**

By summing up the total intake air required for the complete mining system it is possible to compute the minimum ventilation shaft dimensions required to service the chosen mining system.
4.0 Choosing the Right Shaft

The size or dimensions of each shaft will differ according to the intended duty for each unit. There are three types of shafts that I have considered in this paper, namely: vertical, decline and inclined shafts.

There are many factors that influence the location and therefore the type of shaft to be sunk. Any mining engineer will know that the shape, size and dip of ore body will dictate where the shaft position should be. In addition host ground conditions and water bearing structures also influence the final location of shafts. Generally speaking there are three types of ore deposits, that is:

a) Narrow tabular deposits (steep & flat dipping – gold, platinum, etc)

b) Wide tabular deposits (coal, potash)

c) Massive deposits (copper, nickel, iron ore)

All of the above deposits can be accessed by vertical shafts except for the flat narrow tabular deposits, which may be mined more economically using Decline or Inclined shafts. The chosen site of a shaft should be such that the best and most profitable use will be made of it when in full production.

4.1 Criteria for choosing a Vertical Shaft

A vertical shaft should be chosen under the following conditions:

- Ore body should be steep dipping
- Ideal for deep ore bodies
- Provides quick access to ore body
- Most economic hoisting method for depths exceeding 500m
- Quicker return on capital investment

Other considerations are that the shaft should be sunk near or close to the centre of gravity of the ore body. The shaft depth
should be sunk to where most or all of the ore will be transported down grade to reach the shaft loading stations. The shaft should ideally cover a five-year production period i.e. minimum life of five years. For aesthetic reasons the shaft should be in a position where the head frame will be out of site of the general public although this really is not a major issue in developing countries.

4.2 Criteria for choosing a Decline or Inclined Shaft

A decline or inclined shaft should be considered under the scenarios:

- Flat dipping ore body
- Shallow ore bodies
- Require high throughput
- Require low initial capital costs
- Want to avoid some of the environmental concerns (headgear)

The decline or inclined shafts are associated with grade constraints and one needs to take these into account. If a decline is used for trackless haulage then the maximum grade recommended is $8^\circ$. However, if used for conveyor belt haulage and the decline are used by rubber tired trackless equipment on regular basis, then $15^\circ$ is the maximum recommended. If used for conveyor belt haulage only, then the maximum grade could be $15 - 25^\circ$ depending on material to be conveyed. If equipment has to be driven up and down to clean spillage, this will limit the gradient.

It is important to note that unfortunately there are no standard designs for circular concrete shafts. Typically each new shaft is designed from scratch to accommodate the particular requirements envisioned by the mine planners. Therefore each shaft is designed and constructed on a fit for purpose basis.
### 5.0 Shaft Comparison

The discussion on design of mine shafts will be incomplete without making the necessary comparison between the different types of shafts. One needs to assess the selection criteria and compare the merits and demerits of each type as part of the design process.

Table 2 below summarises the selection criteria including the advantages and disadvantages of each shaft type.

<table>
<thead>
<tr>
<th>Shaft</th>
<th>Selection Criteria</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Vertical | Steep dipping ore body  
Deep ore body | Quick access to deep ore body.  
Efficient at depths exceeding 500m.  
Cheaper per metre as depth increases.  
Early return on investment | Highly skilled labour required  
High labour cost  
High initial capital costs  
High maintenance costs  
Require headgear  
Limited hoisting capacity  
Require constant power supply |
<table>
<thead>
<tr>
<th></th>
<th>Flat dipping ore body</th>
<th>Shallow ore body</th>
<th>Can be mined in the strike or dip direction of choice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decline</strong></td>
<td></td>
<td></td>
<td>Easy access to shallow ore body</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low initial capital costs (no headgear)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low operating costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Construction skills and equipment readily available</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High hoisting capacity with conveyor belts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Longer distance to ore body</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Only economical to 500m vertically</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Excessive travelling time to ore body</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Trackless hauling is slow and congested</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heat pickup from rock over length</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Slower return on capital invested</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water handling can be problematic</td>
</tr>
<tr>
<td><strong>Inclined</strong></td>
<td></td>
<td></td>
<td>Derailments</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shaft maintenance &amp; repairs time consuming</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spillage cleaning is time consuming</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Limited hoisting capacity</td>
</tr>
</tbody>
</table>

**Table 2: Shaft Comparison**
Table 3 below gives some indicative development costs. It is difficult to get the exact figure as costs are influenced by support applications, ground conditions and various other factors specific to each site. The numbers used here are the August 2007 costs using an exchange rate of R7.00 to the US dollar. These figures do not include shaft equipping.

<table>
<thead>
<tr>
<th>Shaft</th>
<th>Dimensions</th>
<th>Advance/day</th>
<th>Cost/metre (Rand)</th>
<th>Cost/metre (US dollar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>6m dia.</td>
<td>3.4</td>
<td>90000</td>
<td>12857</td>
</tr>
<tr>
<td></td>
<td>7m dia.</td>
<td>3.4</td>
<td>100000</td>
<td>14286</td>
</tr>
<tr>
<td></td>
<td>8m dia.</td>
<td>3.4</td>
<td>115000</td>
<td>16429</td>
</tr>
<tr>
<td></td>
<td>9m dia.</td>
<td>3.2</td>
<td>135000</td>
<td>19286</td>
</tr>
<tr>
<td></td>
<td>10m dia.</td>
<td>3.2</td>
<td>160000</td>
<td>22857</td>
</tr>
<tr>
<td></td>
<td>11m dia.</td>
<td>3.0</td>
<td>185000</td>
<td>26429</td>
</tr>
<tr>
<td>Decline</td>
<td>5.0m x 4.0m</td>
<td>4.5</td>
<td>40000</td>
<td>5714</td>
</tr>
<tr>
<td></td>
<td>8 deg.</td>
<td>4.0</td>
<td>46000</td>
<td>6571</td>
</tr>
<tr>
<td></td>
<td>10 deg.</td>
<td>4.0</td>
<td>46000</td>
<td>6571</td>
</tr>
<tr>
<td></td>
<td>15 deg.</td>
<td>2.7</td>
<td>52000</td>
<td>7429</td>
</tr>
<tr>
<td></td>
<td>20 deg.</td>
<td>1.3</td>
<td>70000</td>
<td>10000</td>
</tr>
</tbody>
</table>

Table 3: Advance and Cost Comparison
6.0 Design Process Summary

The whole shaft design process can be represented in a flow diagram as shown in Figure 1 below.

![Flow Diagram](image)

Figure 1: Shaft Design Process Flow
7.0 Conclusion

It is my hope that the information contained in this paper will be of some value to some mining engineers who may in the future suddenly find that they need to design a shaft or shafts for a newly found ore body or indeed existing ore reserves. The methodology or process is virtually the same and one cannot avoid the optimisation process to come up with the best economic option.

8.0 Acknowledgements

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