The past, present and future of shotcrete at Elandsrand Gold Mine

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Synopsis

Elandsrand started shotcreting back in 1991. This paper will share the experiences of the mine by looking into the past, the present situation and the way Elandsrand plans to approach the future. It looks at the application of drycrete and discusses the factors that led to the introduction of wet fibre reinforced shotcrete. The logistical constraints of getting shotcrete material underground will be solved by the development of an underground batch plant, using run of mine waste rock as an aggregate.

Introduction

One of the greatest challenges facing the South African mining industry is the establishment of a sound support strategy that will suit the needs of deep level tunnelling operations.

Many factors and parameters have to be considered when attempting to design a support strategy for a deep level tunnelling operation. Factors directly affecting the support strategy are...

The rate of advance

This is probably the most vital factor as it is a well-known fact that traditionally the support activity within a cycle of operations is the most critical activity. In the South African deep level mining context the supporting of a tunnel has always slowed down or hindered the cycle and has never really found a comfortable position within the cycle of operations in which it can be completed. In order to advance at any appreciable rate, this activity has to be synchronised into the cycle of operations so that a smooth follow on of activities can produce the required advance rate. In terms of an ultra-deep operation, a high advance rate would be required to lure any prospective investors and for this reason the supporting of a tunnel is prioritized with the main aim being that of designing a support system that is sufficiently safe, environmentally friendly and cost effective.

What are our needs?

Besides the obvious physical needs as set out in our vision, the mine required a system that could be moulded into our existing process and infrastructure without causing any undue havoc.

We require a system that:

➤ does not pose a logistical threat by reducing the already strained shaft availability. This factor is extremely sensitive especially when considering that all the material required would need to travel vertically via a sub-shaft system and then be transported horizontally for up to 4km on average to the point of delivery.

➤ a system that is user friendly and thereby allows for easy integration into a cycle of operations that is run at high efficiencies in order to achieve advance rates that will ensure our survival (300 m plus).

The depth of mining and the ground conditions

An array of support systems are available within the industry from which a choice can be made. The following is a list of but a few of these choices.

(i) Mesh and lacing
(ii) Roofbolting
(iii) Combined 'mesh and lacing' and roofbolting
(iv) Roofbolts combined with drycrete
(v) Roofbolts combined with drycrete and 'mesh and lacing' (post and/or pre-shotcrete)
(vi) Roofbolts combined with wetcrete
(vii) Roofbolts combined with wetcrete and 'mesh and lacing' (post and/or pre-shotcrete)

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After extensive research and consultation with rock mechanic experts it was decided that in the case of the Elandsrand Gold Mine situation where tunnelling at high rates of advance will take place at ever increasing depths, initially the best options were those given of examples (iv) and (v). When considering the required rates of advance, the ground conditions and the available infrastructure, it was well noted that this new system should be moulded into our existing mining process, rather than trying to change the whole process to suit the single task. Furthermore, it was realised that what lay ahead, or should we rather say what lies below, will not be a simple task.

From all the systems listed, it was only the dry-mix and wet-mix shotcrete that would be new to us. As experience was gained and various dry mix applications were tested, the mine then found itself in a position to increase its demands on the system in order to realise its vision. Hence the introduction of wet mix shotcrete in mid-1997.

The future, as will be seen at a later stage holds great promise regarding shotcrete in the South African mining industry. These new and fresh ideas that will be introduced on the mine in the not too distant future could forever change the way we look at shotcreting operations with regards to logistical issues.

The Elandsrand Gold Mine experience

The vision

The vision of the mine is to engineer a working environment that is:

- totally supported
- consistently safe and
- environmentally friendly

at depths between 3000 m to 5000 m.

The vision as set out above might seem to be the norm in industry but when taking a closer look at the parameters affecting each of the requirements mentioned, we enter a new realm regarding support strategies. One wonders how many mines around the world can truly say that they comply with this vision. In our opinion we can honestly say that we are close to achieving this.

The past

In the context of this case study, the past refers to the period of mid-1991 to mid-1997.

Prior to 1991 the mine made use of ‘mesh and lacing’ and roofbolting combinations to fulfil the support requirements. After careful deliberation and the obvious economic constraints set upon the mining industry the team at the mine had to consider a new approach regarding support. The mine simply had to find a more effective way of supporting our tunnels. The method of choice would have to be both cost effective and effective in application.

In view of the situation presented to us, the only reasonable option available was the use of the well tested and proven method of dry-mix shotcrete (gunite). With this method came the added advantage that the equipment used (piccola, springbok, aliva, rockcreter etc.) were readily available.

The strategy

With specific reference to shotcrete (dry mix), the initial strategy was to introduce this new system gradually but yet forcefully so that our vision received a good kickstart without causing any complications.

The idea was to ensure that all applications be 25mm thick, in accordance with application time constraints and sound rock mechanic practice. Furthermore, all tunnelling bellow 76 level (-2304 m below datum) be covered with each application taking place after the blast during a non-production shift with a maximum lag of 6 m behind the face.

Equipment

After several years of trial and error, two pieces of equipment have proven to suit the needs of our mine most effectively. They are:

- The pressure vessel (See Figure 1)
- Rotary spindle type mechanism (Rockcreter - mini max, Springbok, piccola, aliva) (See Figure 2).

Merits of equipment

The pressure vessel

- This vessel has no moving parts and the time and cost of maintenance is therefore drastically reduced.
- These vessels are filled with 1 m^3 of drymix on surface at a bulk batch plant and are then transported via the network to their destinations. The fact that batch plant mixing on a bulk scale occurs is, on its own, an indication that the quality of the mix will be far more superior than hand mixing on site.
- The mechanism only requires 2 employees for the application process and a further 5 people to operate the batch plant which reduces the normal labour complement of 6 people per application site drastically when using the rotary spindle type mechanism.
- During the extensive use of this piece of machinery, it was found to be particularly useful for large excavation applications which lie close to the shaft station areas.

The rotary spindle type mechanism

- All the rotary spindle type units are small, which make them extremely useful in a wide range of applications. Because of their size and ease of transportation, they have adapted very well to scattered applications in far-lying areas such as tunnelling operations.
- These units are readily available from a number of manufacturers offering good back up services.
- The capital expenditure associated with these units are very reasonable, making the purchase of more equipment for scattered applications far more viable.

Demerits of equipment

Pressure vessel

- The size of the vessel causes immense problems with regards to its efficient transportation over large distances. The success of the application when making use of this unit is largely dependent on its punctual delivery which is often not realised because of its size.

Unless the aggregate is kiln dried, hydration will occur due to the moisture present which leads to total wastage. For these reasons, the pressure vessel is not suitable for applications involving long tramming distances such as tunnelling operations.

Rotary spindle type

- This mechanism has numerous moving parts (air motor, rotor etc.) which invariably result in wear and tear leading to increased time and costs of maintenance.
- This application process when conveyed on a large scale requires bulk hand mixing which results in reduced quality of products and substantial wastage of material. The option to make use of a pre-bagged mix is available and will reduce this disadvantage tremendously.
- During the application process, a material car is required to be in close proximity in order to feed the machine with the mix. For every application shift this could lead to several extra pieces of rolling stock being utilized.

Quality

When looking back over the past 6 years during our use of drymix shotcrete, we have come to realise that although we have effectively introduced this new system to the mine, we are still a far way off from our vision.

The fact is that in the past the shotcrete was too far behind the face to even act as a temporary support. Things have changed where we now manage to apply the membrane within ±1m from the face. The quality of the product has always been questionable given the fact that a lot of hand-mixing takes place which reduces the accuracy of admixture addition. When conducting bulk hand mixing it is often the case that a large proportion (up to 10%) of the material is wasted. Premature hydration also causes a lot of problems especially with the use of pressure vessels which acquire a kiln-dried aggregate to function properly. A kiln is costly but this problem is often overcome by adding more cement by ratios. Environmental issues such as working conditions during the application is also of concern where levels of dust are excessive and sometimes even unbearable.

In conclusion of our past experience, it must be noted that although we did not realise our vision, we did pass through a learning curve that equipped us with invaluable experience for our attempts that followed.

The present

The present is concerned with the period of mid-1997 onwards. This period is governed by one major change, the change from drycrete to wetcrete methods. During this period the wetcrete system was successfully introduced into the mine. Not coincidently it is being introduced in conjunction with a Hi-speed Tunnelling Project (mechanised) currently being undertaken on a phased basis at the mine. The main driving force behind this change is due diligence. Due diligence simply means ‘taking care’. We as a team at the mine feel a moral obligation towards our workforce and hence need to take any reasonable precaution towards ensuring that they are not exposed to unhealthy working conditions.

The changing needs that have prompted this move are as follows.

- Rates of advance

  As we reach greater depth, the distance of ground to be covered in order to open up our ore reserves becomes increasingly longer. Strictly speaking it would be accurate to say that the investor’s confidence is directly proportional to our rate of advance of our tunnels. It is for this reason that an alternative method of supporting these high speed tunnels is introduced. This very supporting task governs our advance rates.
- Task to process

  In order to achieve the desired productivity, the mind set of our employees needs to be changed. A cycle of operations which results in a single blast or advance consists of a number (10) separate activities. The fact is that each of these activities are seen as separate tasks and responsibilities. This thought pattern on its own results in an enormous loss of time and hence productivity as the people responsible for a certain task consider their work done once their task is complete. The need to change this behaviour is of paramount importance. We need a cycle of operations where all crew members understand that no single task is a separate unit, but instead that it is a part of a process which if carried out effectively will result in increased productivity.

  Furthermore, traditionally the specialized tasks within a cycle of operations have been carried out by dedicated teams. A cultural and behavioural transition must take place by multi-skilling people through training in order to equip a single crew or team with the ability to carry out several required functions or tasks during a given cycle.

  Due to the way shotcreting is done on the mine (contractor basis), it is unfortunate that the task of support has been seen as an ‘outsider’ activity. Furthermore, the drymix application does not allow this task to take place during a production shift as it produces far too much dust. With wetcrete we now find ourselves in a position to allow shotcreting to take place during the production shift and therefore allowing it the opportunity to become an integral part of the process.
- The new Health and Safety Act

  Changing legislation regarding the health and safety of our employees is forcing us to take a closer look at all our practices. We have always regarded the health and safety of our employees as extremely important, but there are certain practices that just cannot be completed without having to make concessions. It is for this very reason that drycreting was carried out during non-production shifts which has ultimately led to it being viewed as a totally separate operation which, as mentioned, results in an unproductive environment. Furthermore, due to the need to ensure the best possible working environments for our employees, we are, through due care forced to look at alternatives in order to improve our conditions.

What are the advantages of wetcrete over drycrete?

- Rate of application

  Wetcreting has the advantage that it can be applied via a wider range of pumping rates by accurate micro-silica introduction which amongst other functions acts as a lubricant. It is commonly found that wetcreting exceeds the capacity by volume per 8 hour shift of the drycrete method by up to three times. Due to the nature of the mix, there is far more effective control of the admixing materials which allows for thicker applications and faster setting rates.

  The drycrete application has the distinct disadvantage that admixture control is difficult. This leads to increased time required to apply a predetermined thickness. In our case a 25 mm thickness is required which often needs several passes to achieve. Adding to the time problem associated with drycrete is the fact that additional support is also required in the form of 'mesh and lacing' in order to comply with our specific support requirements. 'Mesh and lacing' is a time-consuming activity and it is only once this has been put in place that we consider our support strategy complete.

- Quality of product

  Wetcreting requires batch plant mixing which lends itself to overall increased control of mix constituents. With wetmix mechanisms, fibre introduction is simple and does not cause any problems. The fibre component combined with correct micro silica quantities ensures

  * easier mixing and distribution of fibres
  * reduced fibre rebound
  * improved bonding between cement matrix and fibres
  * the fact that fibre can be easily introduced with wetcrete is of immense advantage. Wet reinforced fibre crete (WRFC) provides sufficient support so that the cumbersome task of 'mesh and lacing' is not necessary.

  Drymix applications are generally associated with hand mixing which reduces the quality of the product. Fibre introduction with drymix methods have proven extremely difficult and usually result in high wear and tear and poor fibre distribution as well as increased rebound.

- Quantity

  Better control of the specific admixtures results in better bonding which ultimately reduces rebound. With wetcrete applications one will find that 10% of the mix will go to cavity filling whilst only 5–10% rebound will occur. During the application, compressed air is added at the nozzle to accelerate the concrete and thereby facilitate compression and adherence to the surface. With too little air pressure one will achieve poor results concerning compressive strength, adherence and rebound.

  With drycrete it is common to encounter 20–25% rebound which increases the material wastage. If the material is not applied before the retardation period has expired then you have to dispose of the whole load due to loss of workability. The dumped material will then have to be loaded and dumped which causes additional unexpected costs. During machine delays or breakdown, one runs a similar risk.

- Environmental conditions

  Due to a decrease in rebound and the nature of the mix one has considerably less dust during application. This also results in better visibility and overall improvement in environmental conditions. The opposite is the result when using dry-mix methods.

Our requirements of the system

After careful analyses of what wetcrete has to offer, it was evident that we could increase our demands in order to get closer to realising our vision.

The requirements are:

- A 50 mm thick application which complies with rock mechanic principles.
- Fibre introduction to improve the fracture energy and/or shrinkage behaviour of the shotcrete.
- The application must take place during the production shift, after the blast as part of the cycle of operations. There must be no lag, with the shotcrete being applied directly onto the face.

Wetcrete makes the above requirements possible and when looking back at our 'present needs' we realise that by its introduction we now can comply with what we set out to achieve initially in our vision.

The Elandsrand Operation

This wetcrete venture was introduced simultaneously with a high speed tunnelling project taking place at 98 level. The mechanized operation is set to achieve advance rates in excess of 120 linear metres per end per month and has set the stage for the true test of wetcrete effectiveness.

A batch plant has been set up near the station which will act as the base from which all pre-bagged material will be mixed and introduced into an awaiting Agi-car via a short conveyor system. The agitator car used for our purpose has a capacity of 3 m^3 and provides the same functions found on a conventional cement-mixer truck.

Once the Agi-car has been filled, it then proceeds with the pump (wetcrete) to the position of application. The pump with its receiving bin is placed in front of the Agi-car from which the concrete mix is deposited by the rotation of the vessel. The pump has the ability to pump at a rate of 10 m^3/hr but 4 m^3/hr is found to be ample for our needs.

Quality

The parameters used to measure the quality of the drymix applications have in our view been accomplished with great success when using this method. Certain delays within the process have resulted in lower than expected application rates but these delays have been caused due to machine breakdowns within the mechanised equipment suite and initial lack of experience on behalf of the people operating the equipment. Once all the growing pains have been overcome it is a certainty that our vision will be accomplished.

To determine the quality of the wetmix product, the following tests have been conducted.

- Cube test
- Bond test
- Fibre test
- Penetration test
- Thickness test

All the results have compared favourably with pre-set standards.

The future

When looking back over the years gone by we do so with pleasure as we now know that we can achieve the standards we so stringently set upon ourselves. We are living in an era of rapid change and it is therefore imperative that we don't stop here, but instead continue to develop and enhance our skills and processes.

Elandsrand Gold Mine is going to go one step further. We as a team are going to prove that the old mining cliché of 'logistical constraint' regarding the shotcrete process does not have to be the norm.

Through all the research and hard work that has gone into making both drycrete and wetcrete work for the mine, we have always been aware of the logistical problems involved. The fact is that this problem only gets worse as we reach greater depths and unfortunately logistical management has always taken a back seat in the race to improve and enhance our technology. We have now reached a point where we realise that this speeding vehicle should slow down somewhat, come to a halt and allow logistics to drive. For a while at least.

The future requirements

In view of any further development regarding logistics the team defined the following distinct requirement:

- We require a system that will provide relief to the shaft schedule. As previously mentioned, shaft time becomes a critical factor when having to manage thousands of tons of material and equipment on a daily basis through a single main artery in an environment that becomes increasingly deeper. By crushing run of mine waste to provide the aggregate for the shotcrete mix, we will drastically reduce the amount of material needed to be transported through the whole system on a daily basis. Per cubic metre of shotcrete approximately 60% of the mass is taken up by aggregate.

The options to consider

Option A (See Figure 3)

The establishment of a bulk crushing and batching plant situated near the shaft on surface from which the mix would be fed via pipelines to the required destinations.

This system would require a pipeline network that would convey the mix vertically through the sub-shaft system and horizontally between the two shafts and from the sub-shaft to each of the twin haulage systems located on the required levels (102, 105, 109 and 113 levels).

Option B (See Figure 4)

The establishment of a similar system as mentioned in Option A, but here it would be set up on 98 level. Run of mine waste produced by the ongoing development will be delivered to the crushing facility for the production of the required aggregate. A pipeline network of four individual lines would be extended from this facility to each of the required levels stations.

Each level will be provided with an Agi-car which will collect the delivered shotcreted from the respective stations and shuttle it to the site of application.

Our Strategy

In considering our strategy we were certain about two things.

- We wanted to supply all operations below 98 level (-2972 m below datum) with the required amount of multi-purpose concrete without having to employ large amounts of rolling stock.
- Wetcrete has presented us with the solution to all our vision requirements and would therefore be the choice of shotcrete. Furthermore, the success achieved by the wetcrete system during the trial phase of the hi-speed tunnelling project proved that our expectations were not unrealistic.

From the above considerations it was obvious from the onset that Option B would best suit our needs.

The fact that a crushing and batching facility which provided the sinking operation with concrete already exists on 98 level (near the ventilation shaft) only strengthened this decision. By implementing this option one would also exclude vast lengths of pipeline for the conveyance of the mix. We would also be preventing the high risk associated with using a transport medium that is critical to our whole process in the sense that it is all we can rely upon.

The breakthrough

One major drawback when producing an aggregate for wetcrete applications is the sensitivity of particle size. If we wish to provide a suitable aggregate, it must comply with the following prerequisites:

- Maximum size

  Because of limitations on pumping equipment and concerns of rebound, particle sizes should not exceed 8–10 mm.
  - Material larger than 10 mm may block nozzles resulting in lengthy downtime.
  - The quality of material 8 mm+ should not exceed 10% as high degrees of rebound and crater formation will be experienced.
- Granule distribution

  The distribution of fine material (content in sieve no 0.125 mm) should remain within a minimum of 4–5% and a maximum of 8–9%.
  - Too little fines gives segregation, bad lubrication and risk of clogging.
  - High fine content increases viscosity and can also make pumping extremely difficult.

Conventional cone crushers as the one already installed at 98 level are readily available but produce a flaky aggregate when crushing to the required size. This crusher also produces large amounts of fines which also don't suit our purposes. Only recently we have been provided with a solution in the form of a Vertical Autogenous crusher which produces an aggregate matching the above-mentioned prerequisites.

The advantages of this system (Option B)

- Shaft time availability

  Through careful planning it was calculated that at the required advance rates of the 4 levels (102, 105, 109 and 113), a maximum of 1500 m^3 of shotcrete will be required per month.
  A simple calculation of the mix composition indicates that 60% of its mass is taken up by aggregate which results in approximately 2100 tons of material per month. With each material car handling 3 tons of aggregate we will save 700 cars from having to pass through the shaft system. Bearing in mind that our shaft system currently handles 200 cars per day on average we would be saving 15% of the shaft time by making use of this system. This extra time will now be available for alternative usage.

- Control of quality

  With a centralized and semi-automated facility like the one we have planned, the control of mix composition is both accurate and easy to maintain. The advantages associated with a good quality of mix are amongst other things:
  - The strength of material providing a secure working environment
  - Less rebound, hence less wastage and better environmental conditions.

- Reduced congestion and rolling stock

  This advantage goes hand in hand with the savings of shaft time. It is these very cars that won't need to travel through the shaft system that also will not require horizontal tramming. With less cars needed to be trammed on a level you automatically reduce any congestion problems and at the same time increases the efficiency of other tramming operations that will still continue to occur. The fact that less rolling stock will be used, also reduces the maintenance costs and time currently being spent on our cars.

- Labour reduction

  With our proposed system being semi automated, we will require a maximum of 5 people to operate the facility. A further three people per production shift per level will fulfil the application activities amounting to 24 people per day. Together with the plant labour a total of 34 people is significantly less than the complement of 57 people which would be needed to complete the tasks when using the current system (present wetcreting).

- Availability of material

  Due to logistical problems it is a common fact that material availability is put at risk. With this system making use of run of mine waste, and by making shaft time more available, we almost totally expel any risk to material availability for shotcrete purposes.

- Quality concrete on tap

  An added advantage associated with this system is that by increasing the plant's output we can provide the lower levels with a supply of concrete that can be used for many purposes such as ore-pass lining, foundation construction, general construction, large excavation construction and concrete pillars.

Conclusion

During the past seven years we, as a mine, have continuously strived to meet the standards and requirements as set out in our vision. In doing so we have gained invaluable experience with regard to shotcrete and the problems associated with its application. In our view, the combination of Option B and wetcrete is the only way that we can ensure that our needs are met. The advantages associated with this combination provide the mine with the solutions to many of our tunnelling problems.

As we have passed through this learning curve we have become increasingly aware of the fact that future investor confidence is largely dependent on the success achieved by our effectively using shotcrete to support our tunnels and enhance our advance rates. One important achievement is that we have not had a single case of a 'Fall of concrete' accident. ◆

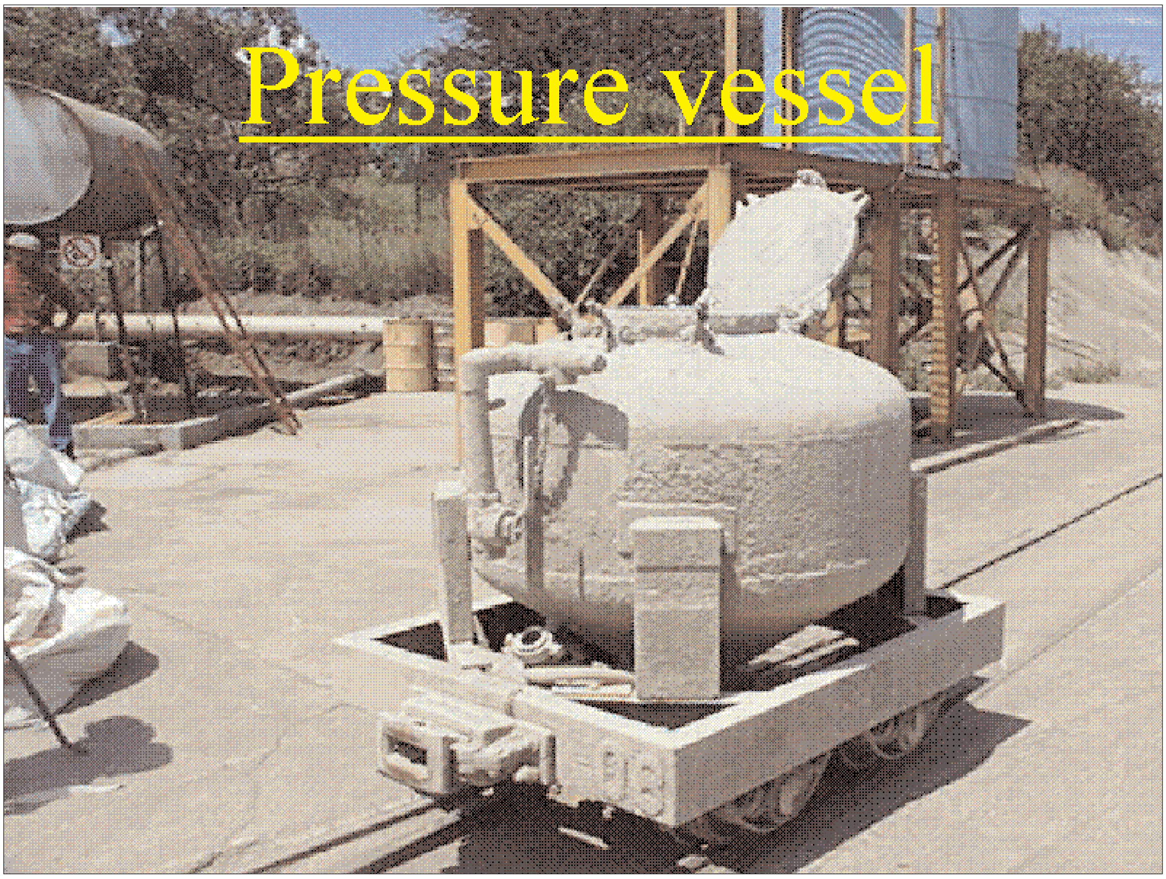

Figure 1

Figure 2

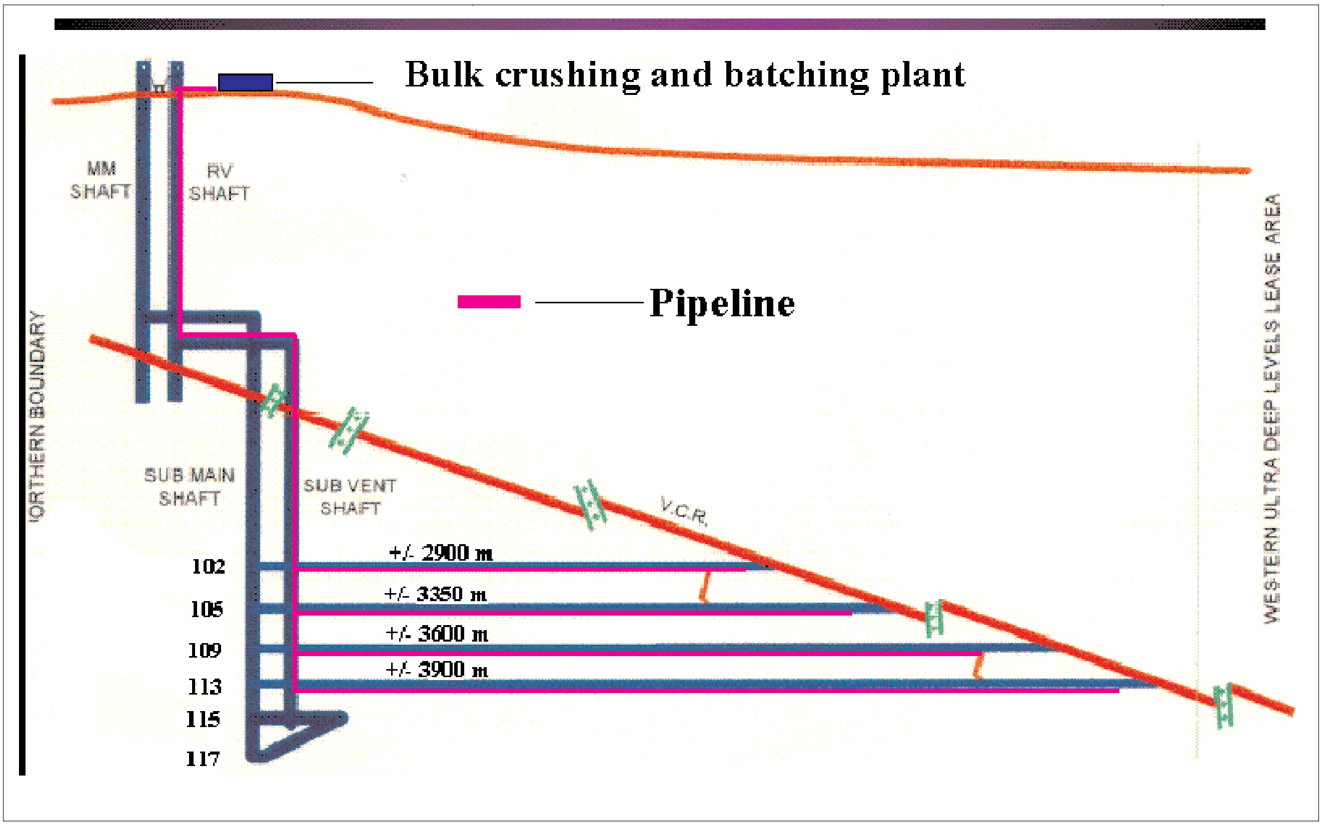

Figure 3—Option A (Surface infrastructure)

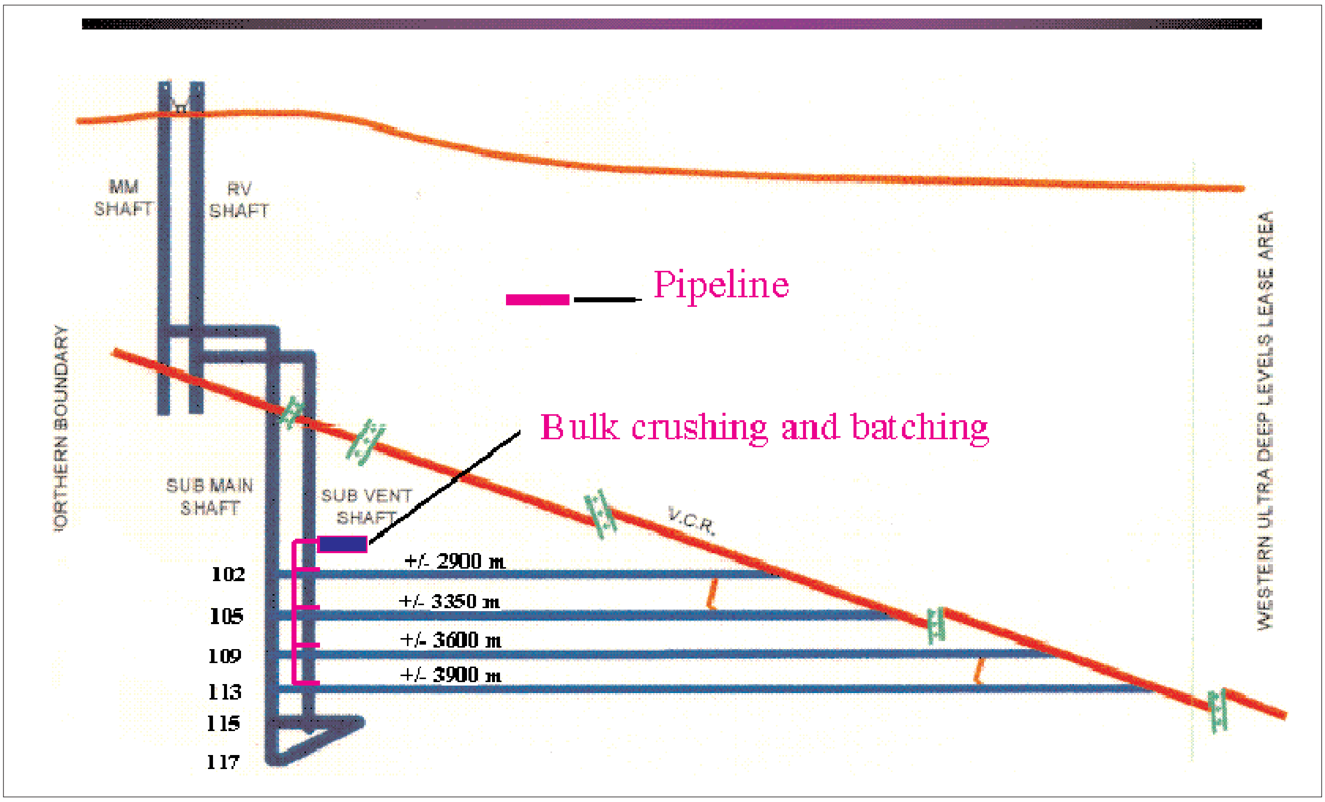

Figure 4—Option B (Underground infrastructure)