Booysendal Central Merensky 1 Portals

Portal Development Breakaway

Munnik, Johan(J), Saayman, Danie (PD)

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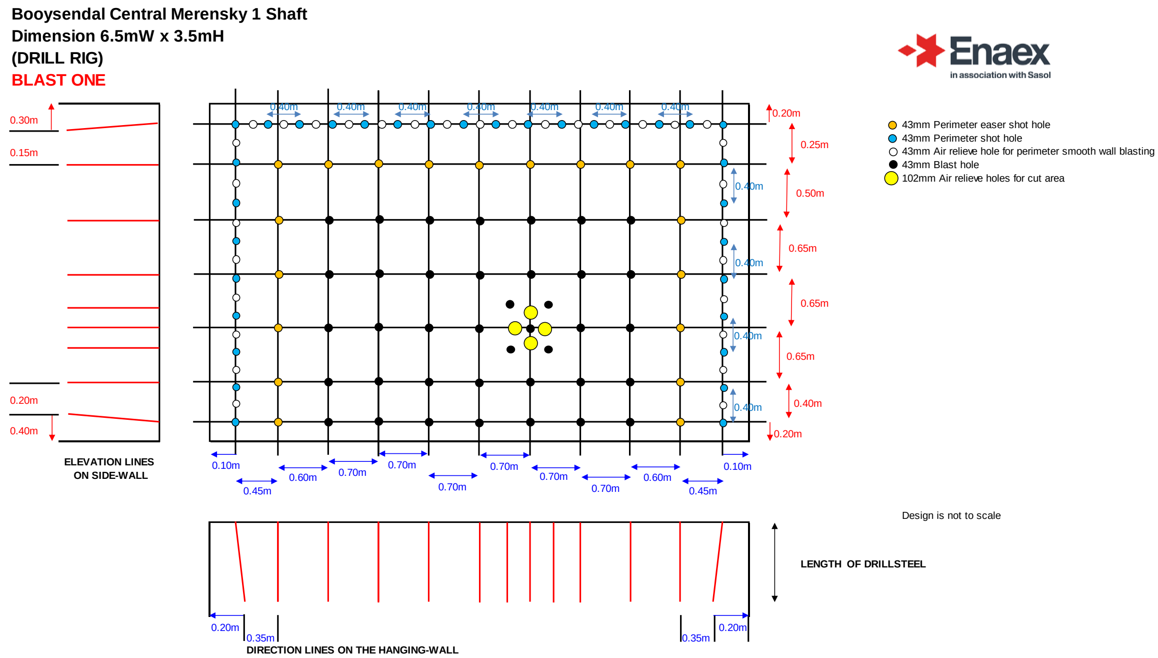
Executive Summary

Booysendal Platinum mine is situated in the Mpumalanga province of South Africa. The mine currently consists of three separate working operations on site namely, UG2 declines, Merensky declines and Central Merensky declines. Future growth required the mine to plan a new operation to enable the mining company to deliver on its future planned targets. The newly planned operation is called Booysendal Central Merensky 1.

The Booysendal Central Merensky 1 complex consists of three portals entering the high wall at an angle of 3º. The nature in the geology required smooth wall blasting practices to be applied to ensure that each portal can be mined safely without excessive over break and falls of ground taking place. The following smooth wall methodologies were applied during the project duration:

- Perimeter smooth wall shot hole spacing's reduced to 57% of original production shot hole spacing.
- Perimeter easer to perimeter smooth wall burdens reduced to 64% on hanging wall and 79% on side walls from original production shot hole burdens.
- Inclusion of air relieve holes between perimeter smooth wall shot holes.
- Reduction in coupling ratio for the perimeter smooth wall shot holes @ 55%.
- Cut design with increased relieve.
- Perimeter smooth wall shot holes charged with Explosmooth™ explosive product with reduced density and energy.

The blast design below was used extensively during the project and all role players applied their skills and knowledge to ensure planned actions were followed. However, when the need arose to make safety and production decisions the whole team was involved ensuring continuity.



During the execution phase of the project all the above methodologies proofed to be effective. However, to distinguish between one or two of them is not possible. They function as a unit and should be utilized together to optimize perimeter control. No major falls of ground and no blast related stoppages was obtained during the duration of the project. It can be said that the below project can be used as a starting point for future projects with similar conditions. Below the picture illustrates the result of the project:

Acknowledgements

To our families:

Thanks for enduring the long hours with us during the duration of the project. We did to a certain degree neglect you during this time as work requirements became more complex. However, you stood by us and for this we thank you.

Enaex Africa Personnel:

The following people were involved from the start of the project and right up to the end ensured that Enaex Africa' name was kept high. They were both the authors of this document including the following two persons:

- Rudi Nieuwoudt
- Joseph Badenhorst

Northam Platinum mine:

Thanks to Willie Theron, Wonderboy Kekana and his team for allowing us to partake and entrusting us in such a major project.

DRA:

Thanks to Eddie Badenhorst and his team for their assistance for the duration of the project.

Booysendal Central Merensky 1:

Thanks to Pieter Kriel, Bertie van Stryp and his mining team for all their assistance during the project.

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ENAEX AFRICA (PTY) LTD 2020/127254/07
Sasol Place, 50 Katherine Street, Sandton, 2146, South Africa
Private Bag X10014, Sandton, 2146, South Africa
Telephone +27 (0)10 344 5000 Facsimile +27 (0)11 788 5092
www.enaex.com

List of Figures

1. **Introduction**

Mr Eddie Badenhorst from DRA Global approached Enaex Africa to assist with designing blast rounds for the new Booysendal Central Merensky 1 shafts. A site visit was conducted on the 10^{th} of December 2018. DRA Global also requested that the designs should follow the same format as that of previous designs done for the Booysendal Merensky and Booysendal Central portals. Cost calculations were also requested. Various documents and information have been shared with Enaex Africa, to assist to the best of our abilities, to produce this document. Appreciation to DRA Global for the continued assistance and sharing of information. This document has been updated after the completion of the project and the inclusion of the execution phase will be added in this document.

2. **Site visit**

The site visit was conducted on the morning of the 10^{th} December 2018 and we were accompanied by Mr K. Paul from DRA Global. The site was being cleared and there were various ecological issues currently being addressed. The high wall was being supported and being made safe. The box cut and removal of waste up to correct level was also underway, and an estimation of the start dates has been shared. Below the photo indicates the position of where the high-wall was being established. The high wall will have a height of approximately 15.0m. The information used in this document was supplied by DRA Global.

Proposed high-wall position

There are currently no limitations on the blasting but a high-tension power cable is in the nearby area (±100m away) and fly rock will have to be kept to a minimum to prevent possible damage to the cable and infrastructure suspending the cable. Below the picture illustrates the position of the high-tension power cable.

High-tension power cable ±100m away

Note: It should be noted that the excavations would be blasted in an incline direction of 3° up to reef intersection. From reef intersection the excavations would turn in a decline direction of -°9 following the reef.

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Sasol Place, 50 Katherine Street, Sandton, 2146, South Africa
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Telephone +27 (0)10 344 5000 Facsimile +27 (0)11 788 5092
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2.1 **Planned mine layout**

Below the image indicates the planned mine layout. Three portals are to be blasted in the prepared high wall.

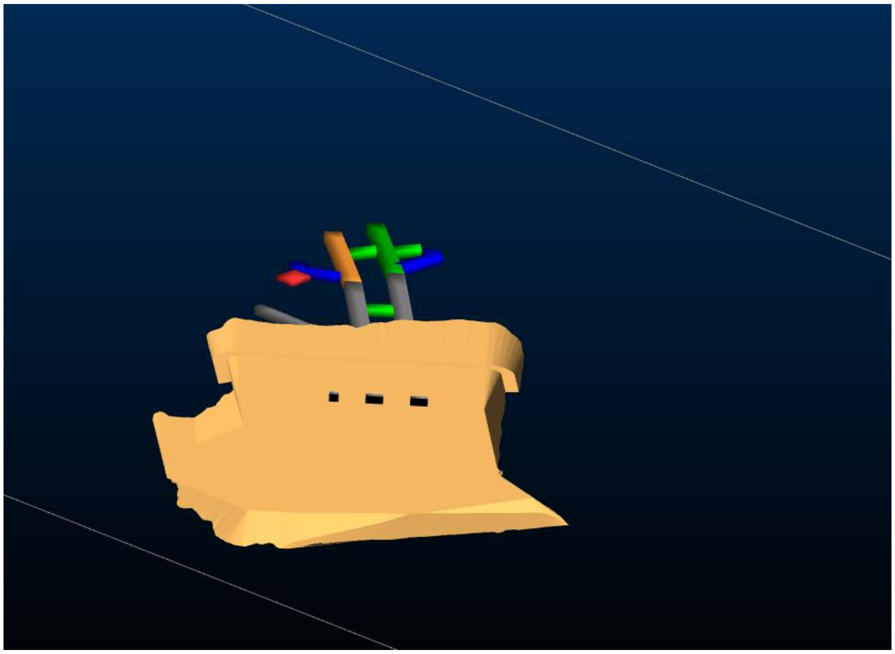

Figure 1: 3D view of three planned portals

Below the picture indicates the planned mining that will take place soon. This illustrates the importance of preserving the entries into the highwall.

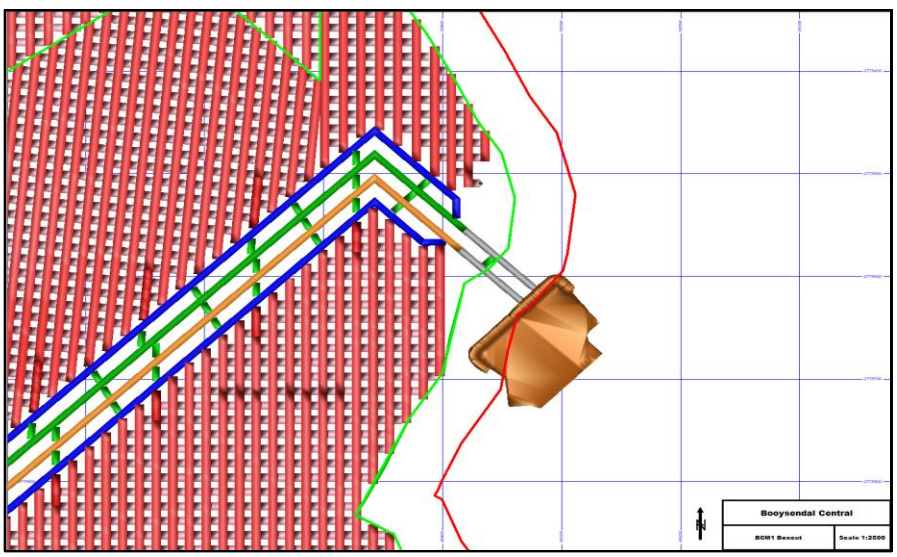

Figure 2: Planned future mining

3. **Blast designs**

The blast designs were based on the previous designs done for the mine whilst blasting the Central Shaft portals. When blasting excavations from surface there are various factors that should be considered when designing a blast. These factors are:

- Rock type
- Rock properties
- Rock densities
- Grade of weathering of the rock
- Geological features
- Blast induced fractures caused by the blasting of the box-cut
- Is there water present in the rock
- Rock hardness
- Limitations placed on the blast. (Eskom)

There are also other factors, but these are the major concerns that will be used when designing a blast.

3.1 **Blasting sequence of the excavations**

Seeing that the excavations would be blasted from surface the following blasting sequencing is recommended (planned).

Slow sink

- 0m to 10m should be blasted using 1.0m shot holes. (dependant on ground conditions)

Slow to medium sink

- 10m to 30m should be blasted using 1.0m to 2.0m shot holes. (dependant on ground conditions)

Medium sink (If ground conditions does not allow for normal sink practices)

- 30m to 50m should be blasted using 2.0m to 2.5m shot holes. (dependant on ground conditions)

Normal sink

- 30m plus can be blasted at full production rounds as per plan if the ground conditions allow for this to take place. Take note smooth walling principles should still be applied.

Please note that a rock mechanic recommendation should be requested for each change in length of shot hole to be made. After reviewing the rock mechanic report and recommendation, can a decision be made with regards to blasting practices. This should be done in consultation with all parties involved. This will ensure that the ground conditions are monitored, and the blast design can be adjusted accordingly if complications in ground conditions are observed. Safety and the integrity of the workings should always take priority.

3.2 Drilling basics

- **Shot holes**

  Drilling would be done using a drill rig. It is recommended that the drill rig use a 43mm drill bit to drill all the cut, production, perimeter easers and perimeter shot holes. All these holes should be flushed clean of excess grit and water after drilling these holes.

- **Cut air relieve holes**

  The cut air relieve shot holes should be drilled using a 102mm drill bit to ensure that enough relieve is created for the round to break into. Although this might seem excessive for the shorter length rounds it should be noted that the size of the hole will assist in preserving the hanging- and sidewalls as well. These holes should be cleared off all water and grit before blasting is to commence.

- **Perimeter air relieve holes**

  The perimeter air relieve shot holes can be drilled the same size as the production holes. These holes should also be cleaned of all excess grit and water before blasting commences. The purpose of drilling these holes is to reduce the spacing distance between the perimeter shot holes. This assist in allowing the perimeter shot hole to vent once the voids of the perimeter air relieve holes is reached. This reduces the amount of energy moving in an upward direction and assist in preserving the hanging- and sidewalls.

Drilling accuracy is a crucial part to preserving the hanging- and sidewall and to ensure a proper break. The drilling should be done by individuals that understands the dynamics of explosives and have in-depth knowledge of how the hole that they drill impact on the blast results.

3.3 **Geology**

Similar geology is expected as that was experienced from Central shaft, however, during the site visit large boulders could be seen, which might complicate the blasting process. The designs however will be kept in line with the relative rock density of 3.1 to 3.2t/m^3. This is slightly lower than what was encountered at Central Shaft.

The design caters for the geology that is expected, but close monitoring of the working place, once blasting starts, will have to be conducted. Drilling discipline will again, as for all the previous projects be critical, and an expert in drilling needs to be enlisted.

No major issues are foreseen when investigating the geology report, received from DRA.

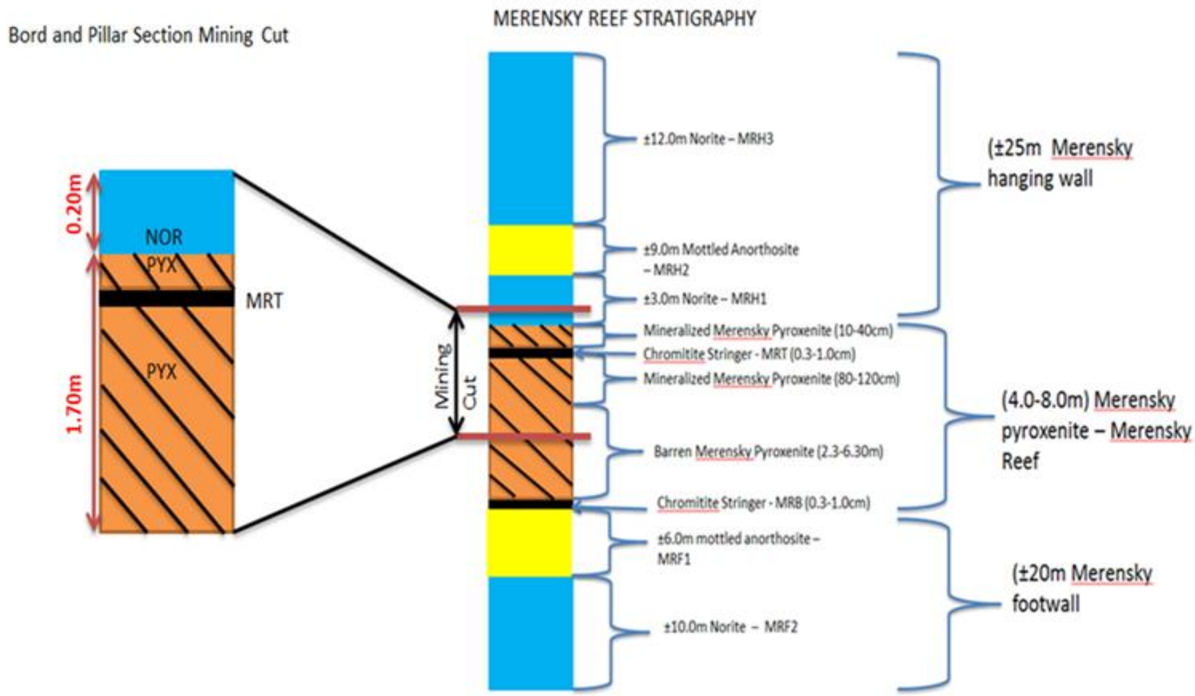

Figure 3: Geology info: compliments of DRA

4. **Project Plan**

A project plan was drawn up with all the necessary steps and procedures that needed to be followed. The project plan drafted was scheduled, and with the very competent ground conditions encountered, the project could be completed before the planned end date.

It should be noted that the project was a huge success due to the team that was present and working on this project. It would not have been such a huge success, if not for all parties involved.

ENAEX AFRICA (PTY) LTD 2020/127254/07
Sasol Place, 50 Katherine Street, Sandton, 2146, South Africa
Private Bag X10014, Sandton, 2146, South Africa
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4.1 **Blast design schematics for various designs**

Please note that two blasts are designed for each dimension. The only difference is that the cut is moved either to the left or right to ensure that no drilling implications will arise due to quantity of sockets in a specific area. There will be three Inclines to be mined, with two dimensions for the three inclines.

4.1.1 **6.5mW x 3.5mH**

- **Blast one**

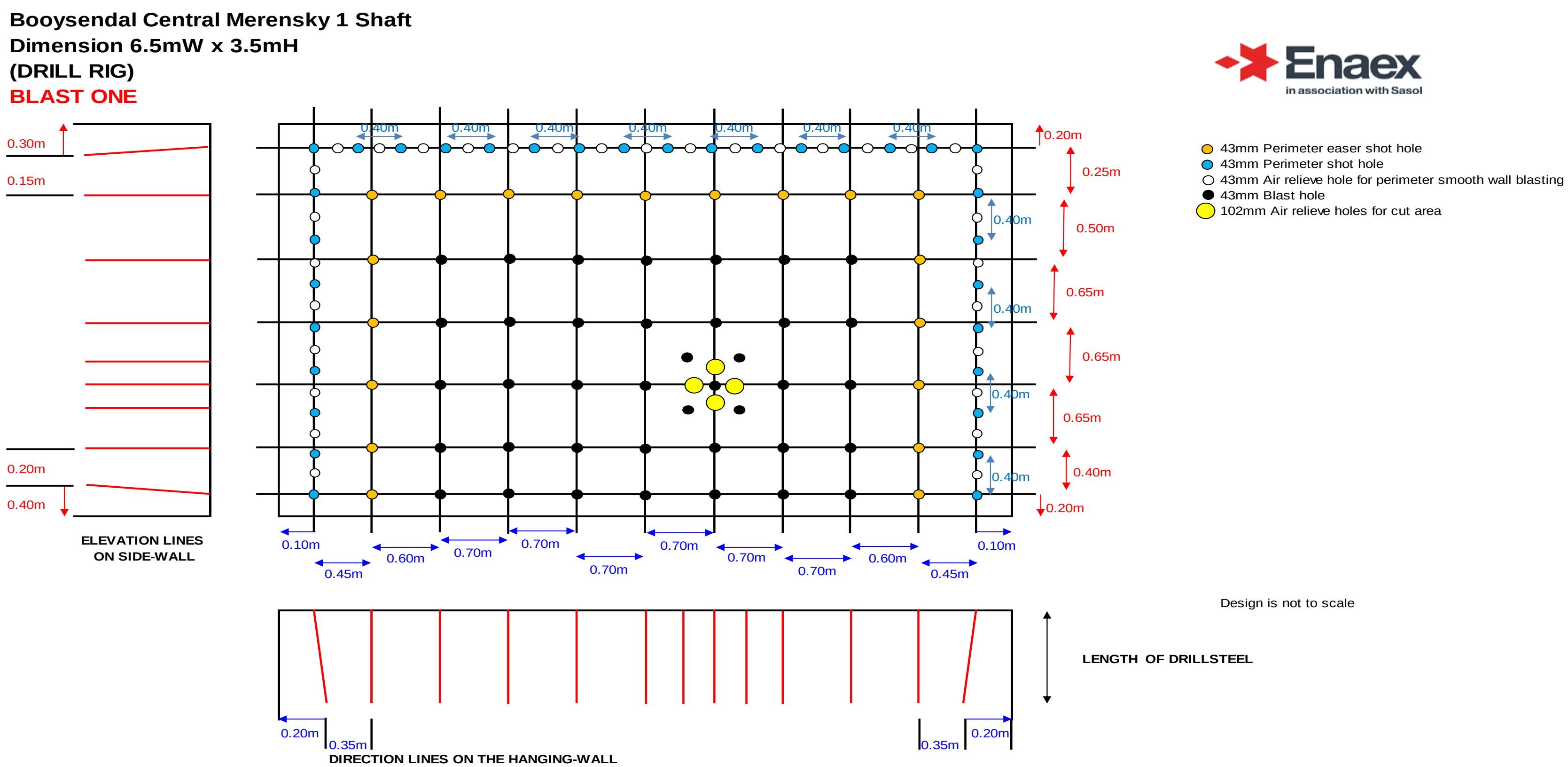

Figure 4: Blast design schematic 1

- **Blast two**

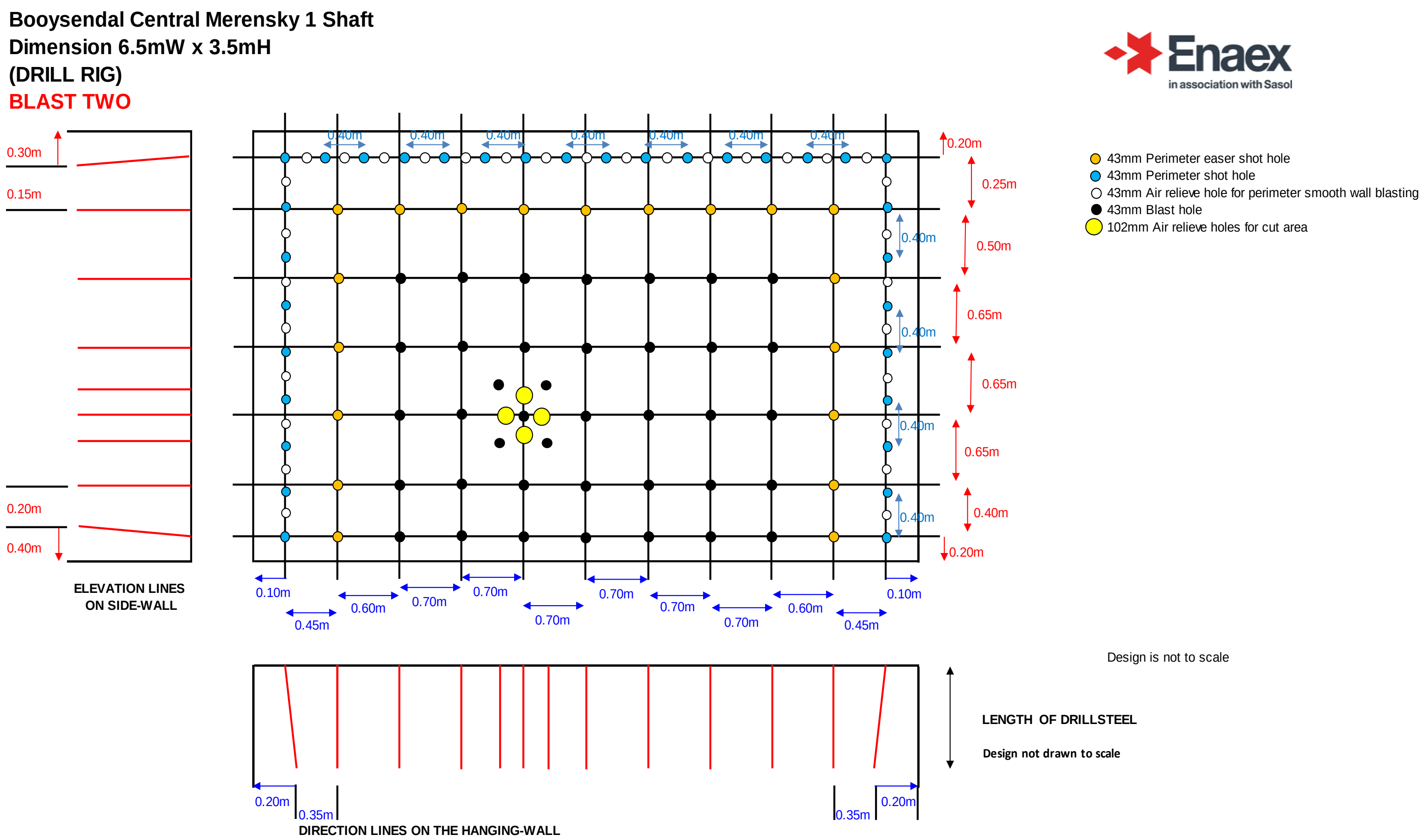

Figure 5: Blast design schematic 2

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Sasol Place, 50 Katherine Street, Sandton, 2146, South Africa
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5. **Products Used**

For the slow sink it is recommended that cartridge products be used to ensure consistency whilst charging and allowing for the decoupling to enhance blast performance. However, should the rock conditions permit it after the initial 10m to 20m and all parties concerned were consulted with, can pump-able emulsions be used for the production and perimeter easer shot holes. It is still recommended to continue blasting the perimeter shot holes with the Explosmooth™ product. This is currently the lowest density and energy product on the market and will yield the best results.

5.1 **Explosives**

5.1.1 **Emex®**

Emex®E70 38X270mm product will be used for the short rounds. This is an emulsion and oil-based explosive. It will be utilized in the cut, production and perimeter easer shot holes. By using a 38mm cartridge in a 43mm shot hole the coupling ratio will be 78% which is in line with general explosive practices.

	Emex® E30	Emex® E50	Emex® E70	Emex® E90
Velocity of Detonation (m/s)	> 4900			
Colour identifier	Yellow	Blue	Green	Red
Nominal density (kg/l)	1.14	1.16	1.16	1.24
Relative weigh strength (RWS)*	90	105	112	115
Relative bulk strength (RBS)*	129	152	162	179
Gas volume (l/kg)	882	868	864	850
Water resistance	Excellent.			
Initiation (25mm hole)	Minimum 6D detonator or 10g/m detonating cord			
Operating temperature (°C)	-10 to +55			
Health / environment	See SDS / MSDS			

5.1.2 **Explosmooth™ 32x550mm**

The Explosmooth™ product is water based watergel cartridge explosive. The reason for using the product is because of its characteristics. The product has a very low density and is weaker than normal explosives used on the market today specifically for the purpose of controlling hanging- and side-walls.

	Explosmooth™	Explogel™V4	Explogel™V6	Explogel™V8	Explogel™V10	Explogel™V12
Velocity of Detonation (m/s)**	4000	3200	3500	3500	3500	4000
Nominal density (l/kg)	0.76	1.05	1.15	1.25	1.18	1.34
Relative Weight Strength (RWS)*	86	90	97	100	105	142
Relative Bulk Strength (RBS)*	82	118	139	157	155	239
Gas volume (l/kg)	834	941	969	978	955	748
Water resistance	Very good					
Initiation (25mm hole)	6D detonator or 10g/m detonating cord					
Minimum diameter (mm)	25+					32+
Operating temperature (°C)	+ 5					

* *Energies calculated using the Tiger Code (JCZ3). (Should not be compared with energies evaluated using other methods).*
** *Velocity of detonation varies depending on cartridge diameter and confinement.*

The Explosmooth™ product is a low energy, medium VOD product which allows for decreased powder factor in the perimeter areas. The coupling ratio of the Explosmooth™ are smaller than that of the Emex® being used (55.4%).

5.2 **Explosive accessories**

For the first 10m to 15m of blasting, it is recommended that electronic initiation systems and electronic detonators be utilized (After 10m to 15m this should be reviewed and should the conditions allow for this then a change to shock tube initiation systems can be made, if not blasting should continue with the Electronic detonators). The reason for this is to ensure accurate timing and the capability of altering timing arrangements to required situations. Single hole firing needs to be applied to ensure that blast vibrations are kept to a minimum. The electronic units also give feedback to the blasting system about their status and if they have fired successfully.

5.2.1 **Daveytronic® Underground Digital Blasting System**

The Daveytronic®UGBS electronic detonator system is a precise and fully programmable blast initiation system. The system is inherently safe and has passed all the safety criteria and carries the CE mark as issued by Inheris France.

General Characteristics		
communication	Bi-directional, 2 way communications	
water tightness	13 bars for 7 days (spool)	
dynamic shock resistance	1050 bar	
operating temperature	-20°C to +45°C	
storage temperature	-40°C to +70°C	
Shelf life	2 years, renewable	
programmable delay times	0 to 14000ms in 1ms steps	
accuracy	±0.02%	
Electrical Characteristics		
electrostatic discharge (ESD) resistance		compliant with SANS 1717-1:2005
electromagnetic interference / compatibility (EMI/EMC)		compliant with SANS 1717-1:2005
overvoltage testing		Compliant with SANS 1717-1:2005
surge testing		Compliant with SANS 1717-1:2005
Detonator Characteristics		
shell	aluminum alloy	
detonator strength	#8	
base charge	PETN 800mg	
initiating charge	Lead azide 200mg	
Detonator downline wire Characteristics		
conductor	steel	
conductor diameter	0.3mm (standard) 0.5mm (premium)	
insulation material	HDPE	
insulation diameter	1.5mm	
tensile strength	320N (standard) 430N (premium)	
abrasion resistance	Compliant with EN 13763-4 (class II)	
Connector Characteristics		
material	Polypropylene (pp)	
insulation	Silicon electrical insulating gel	
terminals	Steel hardened & tined	

5.3 Charging methodology utilized

The holes should be charged in the following formats:

- **Cut, production and perimeter easers shot holes**

  All holes were cleaned of water and grit. After cleaning the shot holes, a primer made up of the Emex® and the detonator were pushed to the toe of the shot hole. Behind the primer a set amount of additional cartridges were placed dependant on the shot hole length. The remainder of the shot hole were tamped using Stemming material. The lengths varied from the planned 1.2m and 1.7m because of practical drilling difficulties.

- 1.2m shot hole contained 1 x 270mm (Primer) + 1 x 550mm cartridge. Resulting in 68% column fill.
- 1.7m shot hole contained 1 x 270mm (Primer) + 2 x 550mm cartridges. Resulting 81 % column fill. When pressed firmly into the shot holes this resulted in approximately 70- to 75% column fill.

Figure 6: 1.7m hole charged. (not to scale)

- **Perimeter shot holes**

  Perimeter shot holes were charged with the Explosmooth™ product. All the holes were cleaned of excess water and grit. A primer was made up with an Explosmooth™ cartridge and a detonator.

  - 1.2m shot hole contained 1 x 550mm (Primer). This resulted in a column fill of 46%.
  - 1.7m shot hole contained 2 x 550mm cartridges (One being the primer). This resulted in a column fill of 65%.

Figure 7: 1.2m Perimeter shot hole charged. (not to scale)

6. **Portal Blasting**

6.1 **Overview of Portal Blasting**

Fifteen (15) days were spent from the first blast taking place on Monday 30 November 2020, blasting the Conveyor decline, up to Monday 18 January 2021 completing the electronic blasting portion of the project. The last blast was done on the Return Air Way (RAW). Below the image illustrate the highwall with the portal positions after being supported and shotcreted before the first blast was taken.

Figure 8:Picture of portals and Highwall prior to first blast

6.1.1 **Advance per blast**

Investigating the fifteen (15) days of blasting and understanding the entire project with the scope with all other parameters taken into consideration, the face advance can then be laid out and analysed. It must be noted that from the planned +-0.9m advance this was never achieved, as the advance was always more than 1m from the first blast. The extra advance achieved is not always a good result, as precision blasting was being done, however in this case it assisted as the ground condition was extremely good and competent.

With the very good and solid ground conditions intersected, together with the rock mechanics recommendations, in partnership with the entire project team, it was decided to increase the length of shot holes and to monitor the conditions throughout the project. This was the main reason for finishing the planned project ahead of schedule.

Below is a picture of the three portals when blasting short (1.2m shot hole) length holes, after the first three blasts.

Figure 9: Three portals after one blast each

The advance per blast gradually increased and the optimum blast hole length of 3.2m could be achieved after reaching ten meters (10m) advance in all three (3) portals.

Below the graph shows the advance achieved for each blast until 30m was achieved combined for the three portals.

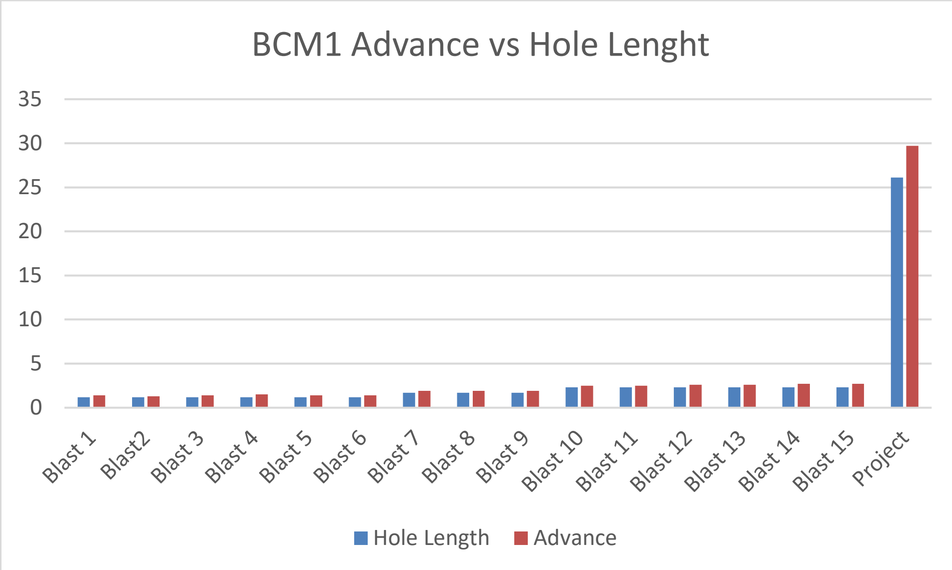


Figure 10:Graph showing hole length vs. advance vs. overall project advance

From the actual results the graph below shows that the advance exceeded the drilled hole length with every blast. It cannot be stressed enough that the good ground conditions intercepted with the quality drilling done, contributed to the good face advance achieved.

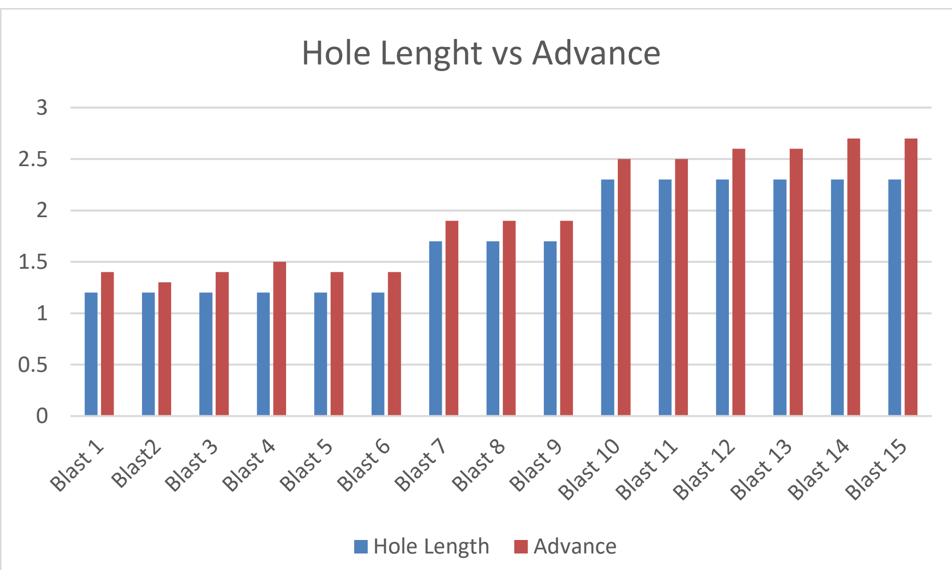


Figure 11:Graph showing hole length vs. advance per blast

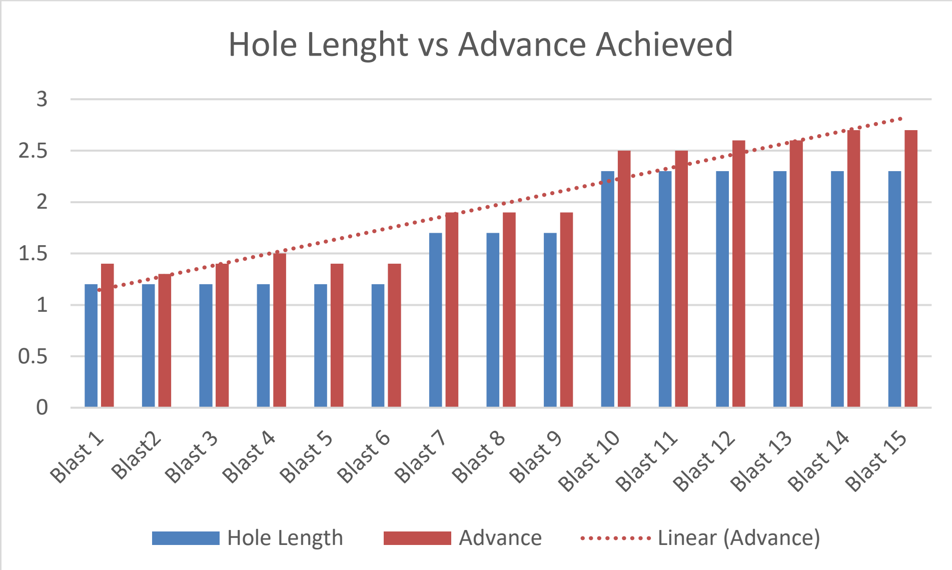


Figure 12:Graph showing the linear increase in advance

The graph above clearly shows the linear achievements from blast one to blast 15, when 30m was achieved, and full rounds of 3.2m could then be drilled and blasted. Blast one (1) to blast six (6), 1.2m hole lengths were drilled. Blast seven (7) to blast nine (9) 1.7m shot holes were drilled. Blast ten (10) to fifteen (15), 2.3m shot holes were drilled and blasted. Please note that the entire project team, together with the Rock Mechanic Department from Northam Platinum Mine, decided when the shot holes should be lengthened. This decision was made purely based on the rock strata observed and encountered. Expertise in underground mining also plays a major role in deciding whether it is safe to change drill lengths or not, and having specialized personnel assisting on a project of this magnitude, is priceless.

6.1.2 **Timing**

When timing is being assigned to each specific blasthole, the knowledge and experience gained from previous similar projects is extremely beneficial, and valuable. But, as learnings from previous similar projects have proven in the past; is that no one project is similar and trial and error and physical blasting the portals will show what

timing method should be used and what model will work the best for the geology present on the day of blasting.
At BCM1 portals, different timing models could be used and experimented with, as to get the best results. With the UGBS system, 14000m/s can be utilized to initiate the blastholes. The 14000m/s is then used in sequence and as necessary. Two models were used during this project.

- fast timing in less than 5000m/s for the entire portal comprising of +-120 blast holes and
- slow timing utilizing as close to 14000m/s as possible to initiate the portal consisting of the +-120 blast holes.

The timing model to be used is purely site specific and the ground conditions will guide the user. The main benefits of electronic blasting are that each blasthole can be given a specific timing delay, and this delay can then be modified to ensure the best possible results are obtained. The absence of any misfires is required for optimum results, and should any misfire be identified, the cause is then investigated and mitigated in the next blast. Misfires is also the reason why timing models can be used, and in this project, the model needed to be changed due to a misfired hole that was encountered.

There are various reasons for misfires, and each misfire should be investigated for the root cause. At BCM1 it was found that the timing was the cause of one incident, and the other was due to the detonator being pulled out of the explosive cartridge being used as the primer, and was immediately rectified, by fastening the bus-line higher than the cut and fastening the detonator wire with insulation tape to the cartridge. Below the two timing models will be explained.

Below is the result after the face has been timed and connected with UGBS busline. Blasting can then commence at blasting time.

Figure 13:The portal after timing and connecting was completed

6.1.2.1 **Fast Timing Model**

Faster timing, timing utilizing less than 5000m/s for +-120 blast holes was used for the first blast as this was the timing model that worked the best at Central Merensky portals. The timing model has given very positive results previously, but the geology and ground conditions were different from the geology experienced at BCM1. Below is the timing that was done prior to timing the actual electronic detonators. This is done due to drilling deviations that might occur, or extra holes that was drilled. It makes it easier to draw the face and then do the timing on paper by hand, as per the exact number of blastholes that was drilled and needed to be blasted.

Different connecting procedures are available for use on the programming unit, but easy one by one timing and connecting has been the preferred method to use and is also very accommodating.

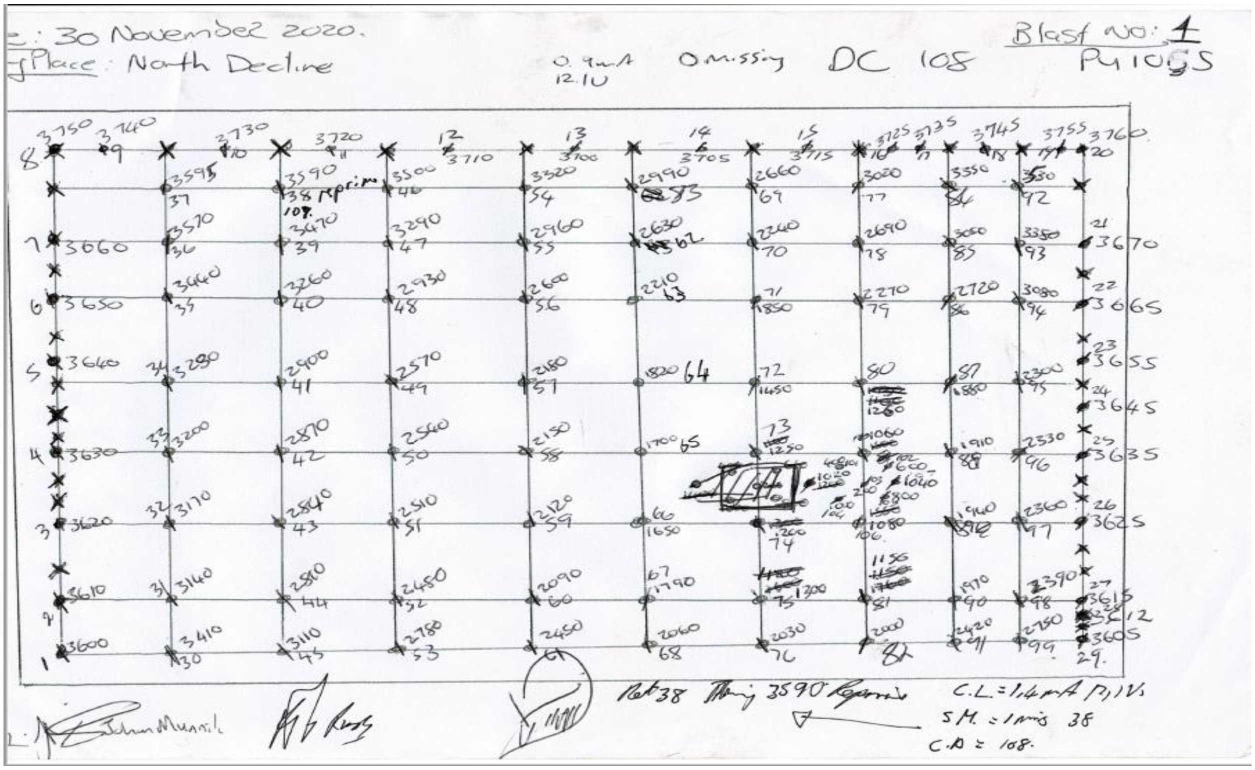


Figure 14: Blast plan for first blast

As can be seen from the blast plan in figure 14, the timing starts at center hole of nine hole cut with 200m/s and ends at the right corner perimeter shot hole with 3760m/s. The entire round which had 108 blastholes, initiated within 4 seconds. This is considered very fast in underground mining practices. However, this method reduces the risk of misfires and reduced the dynamic shock on the detonators when blasting in previous projects. This model unfortunately produced one misfired hole on blast one.

The timing was duplicated on blast two with timing ranging from 200m/s to 4090m/s at the last blasthole. The primers were carefully made-up to eliminate the risk of detonators pulling out from the explosive cartridge. Unfortunately, the same result with one misfire experienced after the blast. Below is the blast plan from blast 2.

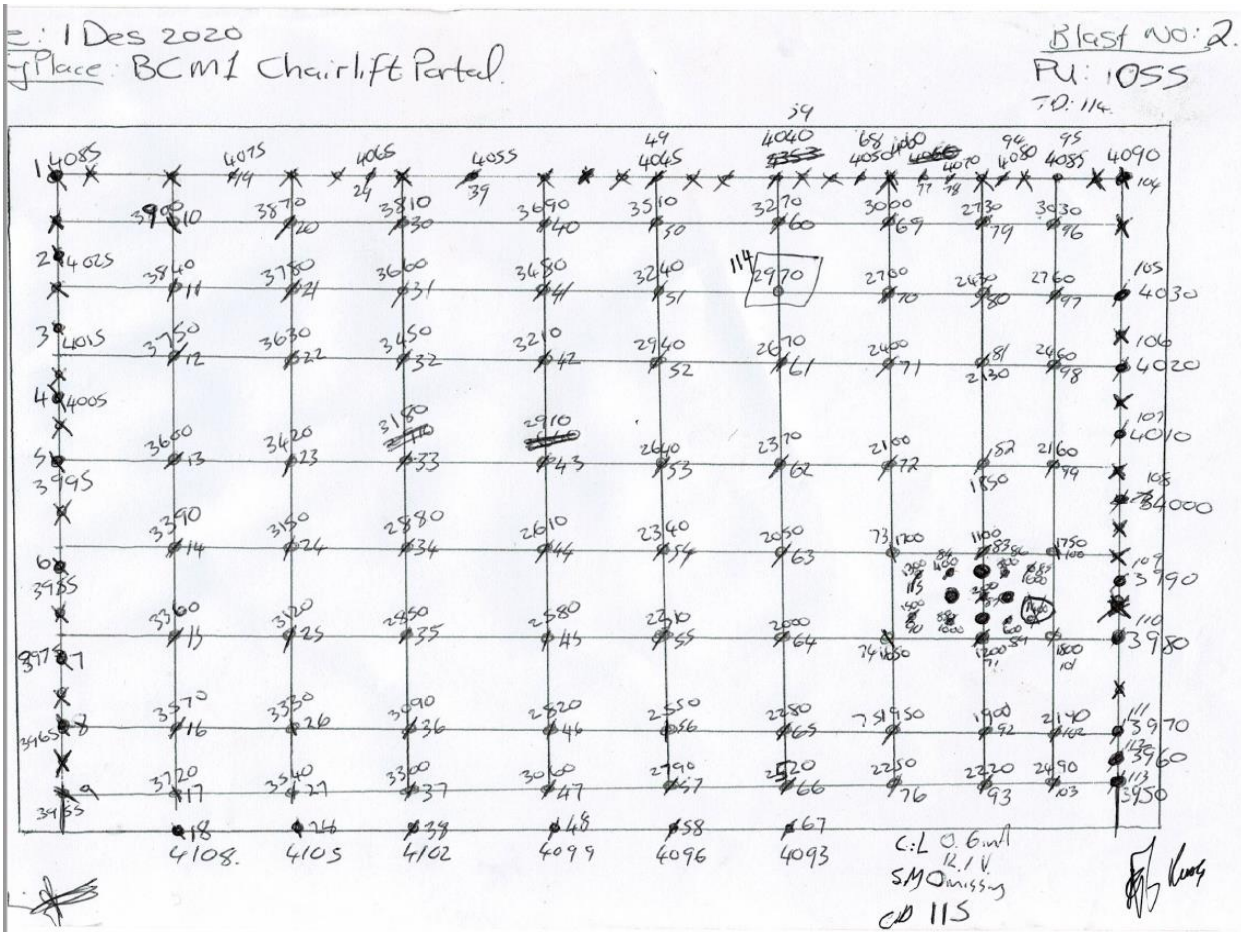
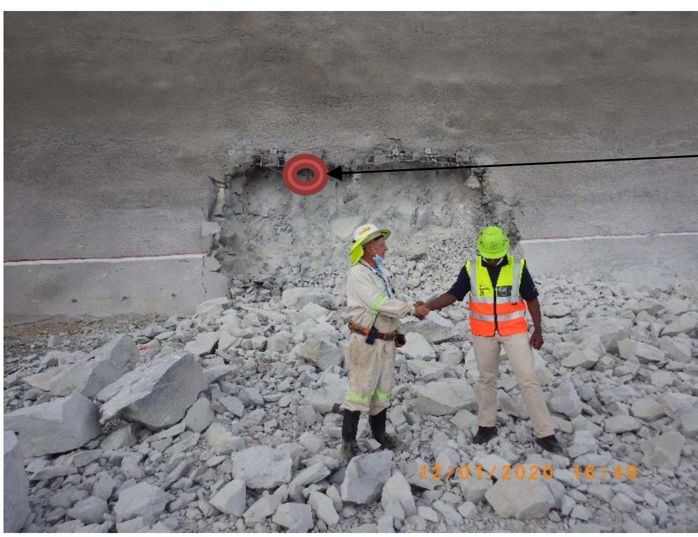


Figure 15:Blastplan for second blast



Hole number 29 on blast plan where misfire was observed

Figure 16:Blast results of second blast

Due the second misfire on the second consecutive blast, it was decided to change the timing model to check whether the slow timing model would give similar results or would eliminate the misfires encountered. The next point will discuss the slower timing model.

6.1.2.2 **Slow Timing Model**

After experiencing two misfires on two consecutive blasts, the decision was taken to give more time for every blast hole. Blasts 3 to 9 and 11 to 15 were all blasted utilizing the slower timing method, with great success and without any misfires encountered. Thus, the timing worked better in this rock formation and virgin ground conditions than what was experienced at Central Shaft portals. The trial and error in every working place, and different conditions should not be underestimated, as different rock types require different applications.

The 12 blasts taken with this timing model was timed from 100m/s for the first cut hole and ending on some blasts at 13950m/s for the last perimeter blasthole.
Below an actual blast plan from the 15th blast taken on 18 January 2021, which was also the last blat taken at BCM1 with UGBS electronic detonators. No misfires were encountered after the timing was changed, and no issues were experienced using the UGBS system.

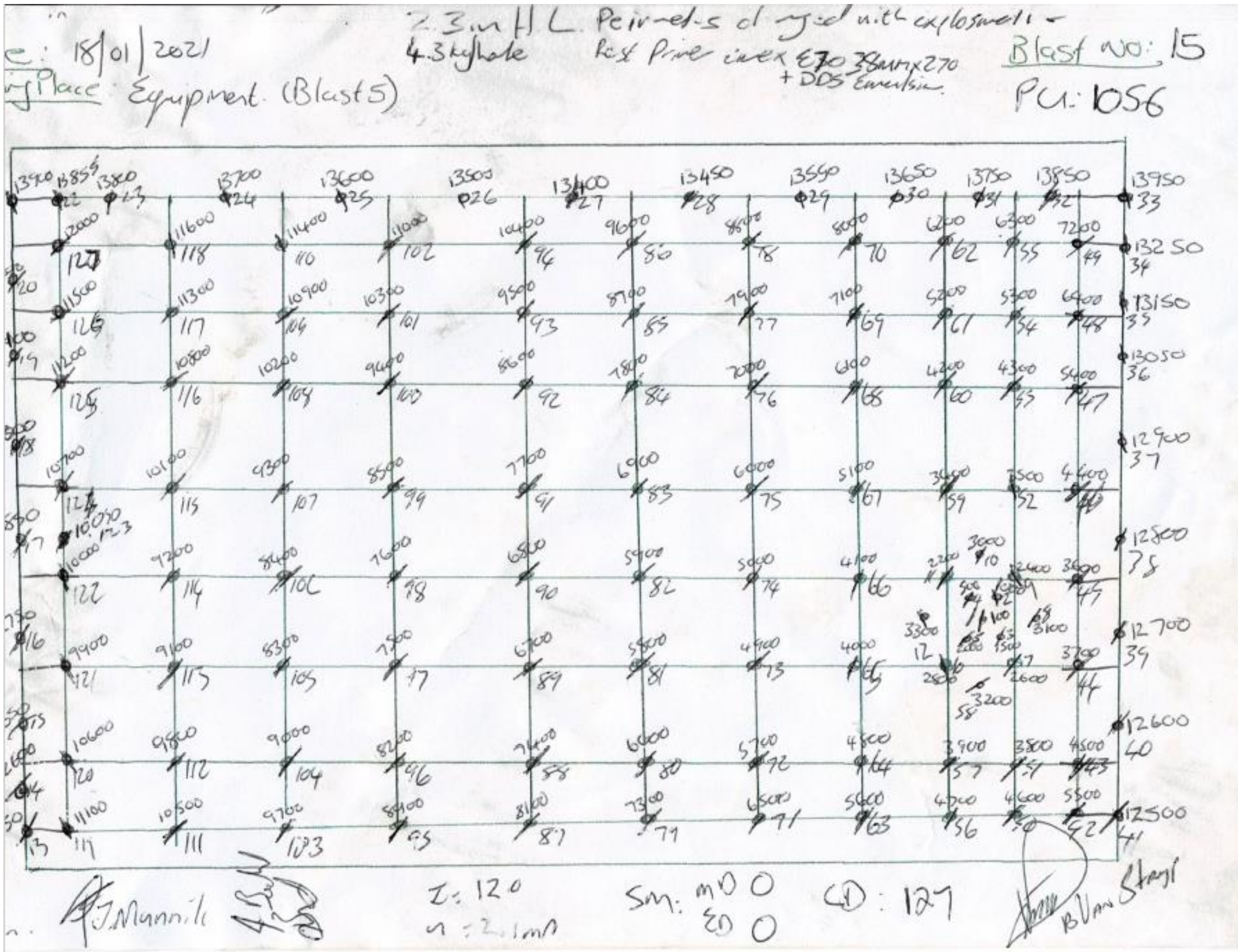


Figure 17:Blast plan form last blast with DTUG System

6.1.2.3 **Multiple portal blasting**

The plan was to always only blast one portal per day, as it would give enough cycle time for the other two portals to be prepared for drilling and blasting. With the last blast before the annual Christmas break taken on the 14th December 2020, and blasting resuming on the 5th January 2021, enough preparation time was available to fully complete drilling all three of the portals prior to starting the break. On the 5th of January 2021, it was discussed to blast two portals on the same day at the same blasting time of 16h45.

The major constraints for this dual blasting, was that due to the Corona Virus, many people were stranded in their countries due to the closure of land borders. The Daveytronic team could also not be on site in time due to logistical issues, and the two portals was timed and blasted with the assistance of mining personnel from Northan Platinum Mine. The team was well experienced mining personnel, and the timing went smoothly without any constraints. The dual blasting however necessitated that the two portals be blasted using a blasting method with the UGBS system that would give the best results, taking into consideration the sensitivity of the surrounding highwall that takes priority. Mono Blast was the option used for blasting both portals.

This is the option that has been used for the entire project, and the method used for the dual blast. This method involves using one or two PU's one DBD and blasting remote. The only difference is that the timing of both portals had to stay within the allotted 14000m/s. This was done by timing the first portal from 100m/s to 6800m/s and the second portal from 7000m/s to 13226m/s. This method worked very well and will also be used in future similar situations. Below are the two blast plans for the two portals that was blasted on the 5th of January 2021 without any damage or misfires observed after the blasts.

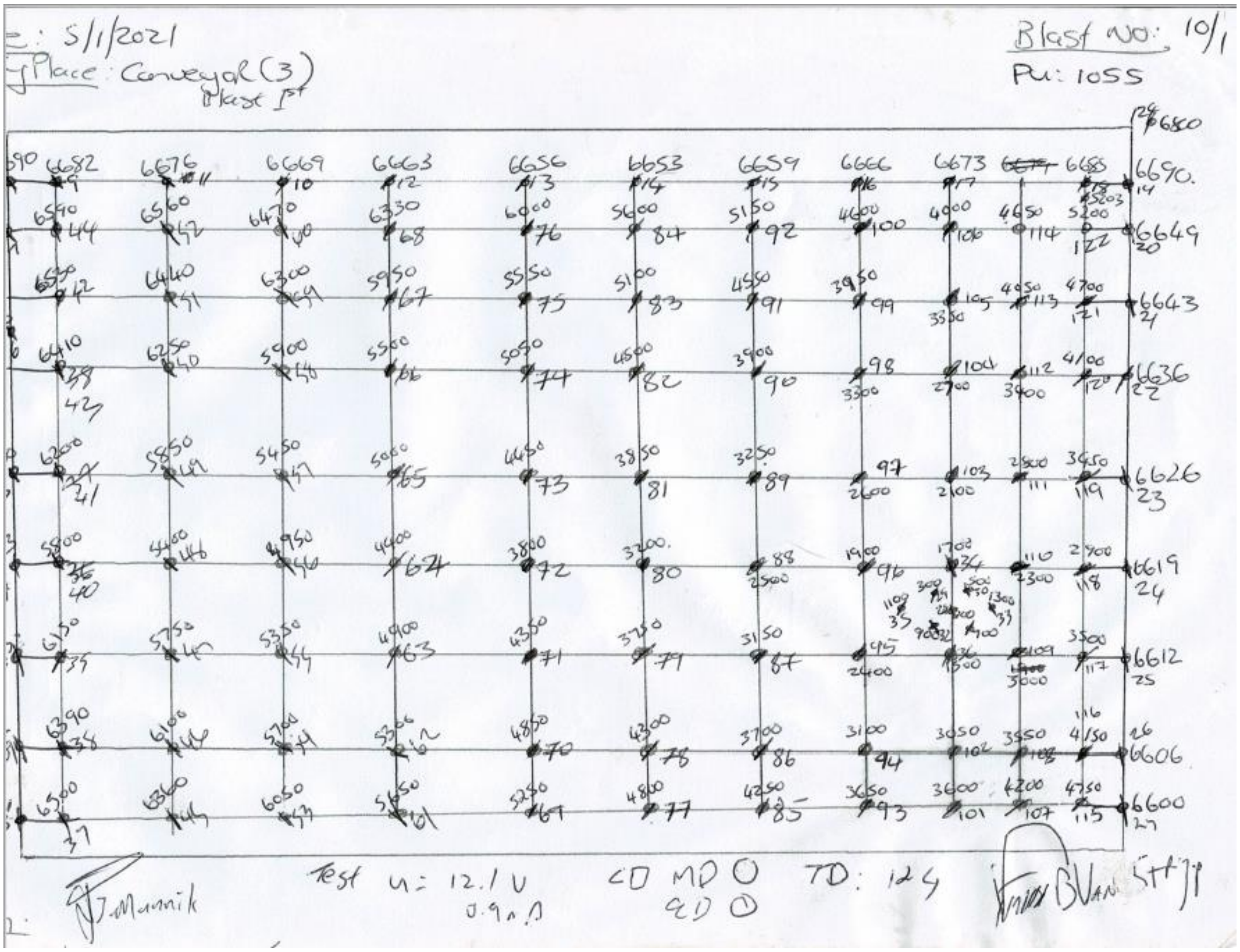


Figure 18:Blastplan of first Dual portal blasting

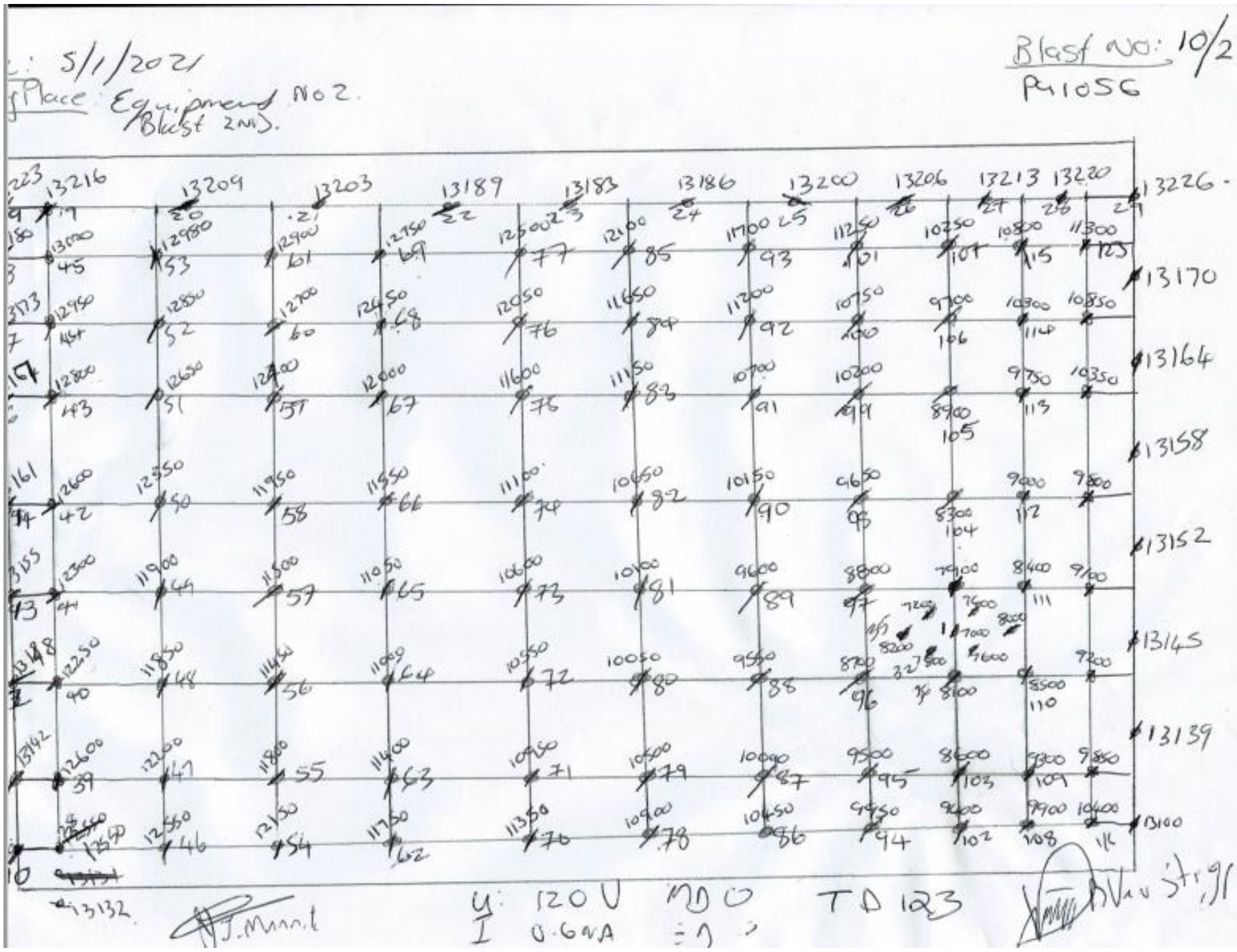


Figure 19:Blastplan of second dual blast portal

6.1.3 **Hanging and sidewall conditions**

The primary objective of the study is to verify the validity of various methods used to protect surrounding rock whilst blasting portals from surface. These methods are:

- Inclusion of air relieve holes between perimeter smooth wall blast holes.
- Reduced burden and spacing between perimeter smooth wall blast holes and perimeter easer blast holes.
- Lower energy explosive charge on the perimeter smooth wall blast holes.
- Decoupling of perimeter smooth wall blast holes.
- Timing to be done as to allow for single shot firing of all blast holes.
- Shorter rounds.

- Increased cut relieve area (Larger void ratio).

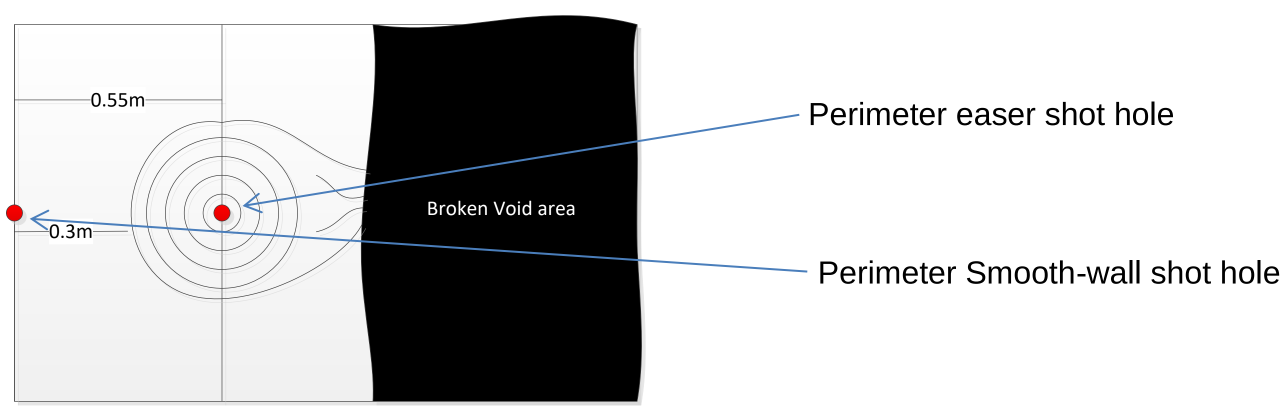
6.1.3.1 **Perimeter Control and relieve**

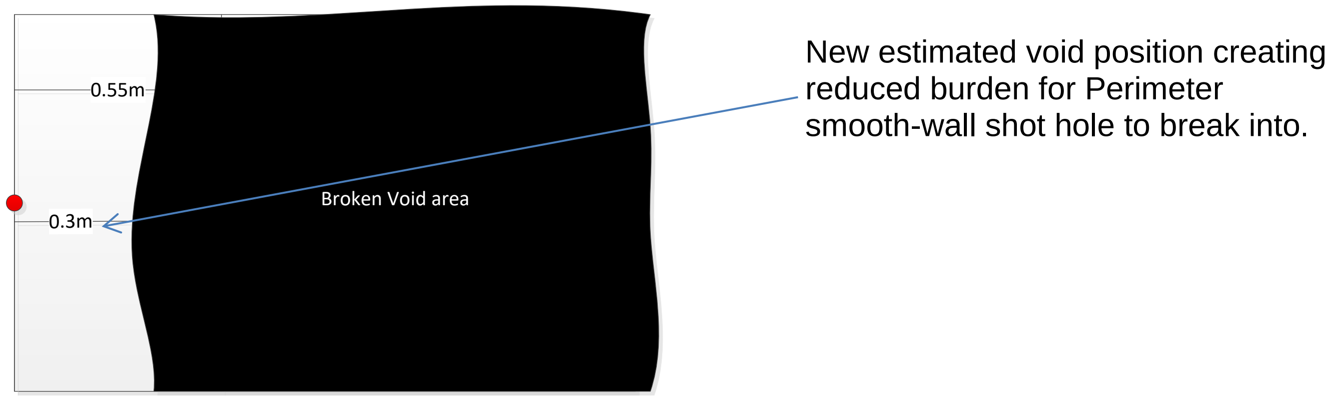
This blasting technique is often used where tight breaking conditions and adverse environmental stresses are present. The results from proper implementation of the smooth-wall techniques was evident from the first blast, as barrels could be seen in the hanging- and sidewalls. This was indicative of very good explosive control, excellent drilling control, and an overall success in the basic mining principles that were implemented.

- **Decreased burden between perimeter easer and perimeter smooth-wall shot holes.**

This method allows for the perimeter shot holes to vent quicker into the void area, causing less energy to move into the surrounding rock mass. Below the sketches illustrates the theory:

  - The perimeter easer shot hole initiates and creates void for the perimeter smooth-wall shot hole.



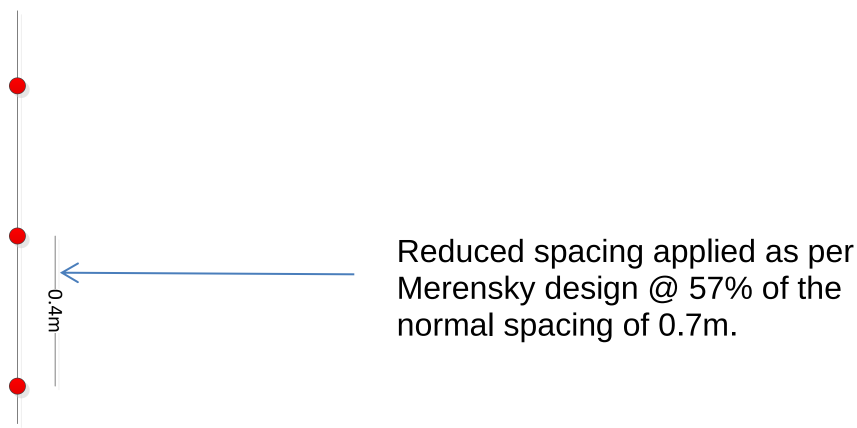


For the blast design the following dimensions were used:

- Hanging-wall smooth-wall burdens were reduced to 64% of the normal burden (0.7m) @ a toe burden measurement of 0.45m.
- Side-wall smooth-wall burdens were reduced to 79% of the normal burden (0.7m) @ a toe burden measurement of 0.55m.

- **Decrease spacing's between Perimeter smooth-wall blast holes**

Decreasing the spacing between the perimeter smooth-wall blast holes fulfill the same function as the above, in that it effectively reduces the burden (spacing wise) of the perimeter smooth-wall blast holes. The sketch below illustrates the reduced spacing as planned.



- **Inclusion of in-fill air relieve holes between perimeter smooth-wall shot holes**

Again, the principle behind utilizing these holes is to assist in reducing the burden of the perimeter smooth-wall shot holes. These holes are drilled at full length and left uncharged during the blasting process. They act as free breaking points for the shot holes. Below the sketch illustrates the in-fill air relieve holes planned for the perimeter.

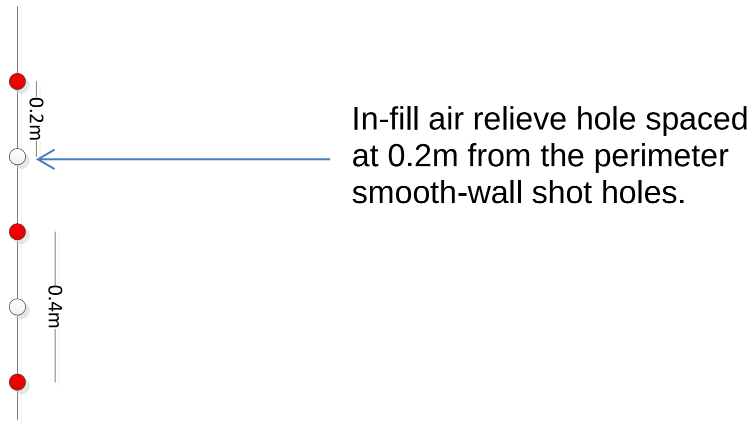


Figure 20:Illustration of infill air relieve holes

The above results in a free breaking point being available for all perimeter smooth-wall shot holes to vent into every 0.2m.

- **Coupling ratio**

The definition of coupling ratio is as follows, - The coupling ratio is the cross sectional area of the explosive cartridge to the cross sectional area of the blast hole (Blasters Handbook Ed 18:373).The following formula can be utilized to calculate the coupling ratio:

$$CR = \left(\frac{d_e}{d_{sh}} \right)^2 \times \frac{100}{1}$$

- d_e = diameter explosives cartridge
- d_{sh} = diameter shot hole
- CR = Coupling Ratio

ENAEX AFRICA (PTY) LTD 2020/127254/07
Sasol Place, 50 Katherine Street, Sandton, 2146, South Africa
Private Bag X10014, Sandton, 2146, South Africa
Telephone +27 (0)10 344 5000 Facsimile +27 (0)11 788 5092
www.enaex.com

The industry norm for use with cartridge explosives is to have a coupling ratio between 70- to 80%. The reason for this is that one would not want to waste explosive gas energy filling the remaining void in the shot hole and higher values result in difficulty inserting the cartridges with the detonator tube into the shot hole. Lower ratios can also be utilized to reduce the explosive energy within the surrounding rock mass. This is usually done when applying smooth-wall blasting practices.

For the BCM1 blast operation the following coupling ratios were utilized whilst planning the blast round.

- **Cut-, production- and perimeter easer shot holes**

Emex®E70 38x270mm cartridges were to be used in these shot holes. This resulted in a planned coupling ratio of 78%.

$$=\left(\frac{38}{43}\right)^2 \times \frac{100}{1} = 78\%$$

- **Perimeter shot holes**

Explosmooth™32x550mm cartridges were to be used in the perimeter shot holes. This resulted in a planned coupling ratio of 55%.

$$=\left(\frac{32}{43}\right)^2 \times \frac{100}{1} = 55\%$$

All these parameters and techniques contributed to the successes of the project, and below the pictures shows the barrels that was blasted during the project.

Barrel on sidewall after blasting

Figure 21:Barrel after blast

Barrel on side-wall and hanging-wall after blasting

Figure 22:Barrels on side-and hanging-wall

6.1.4 **Final product**

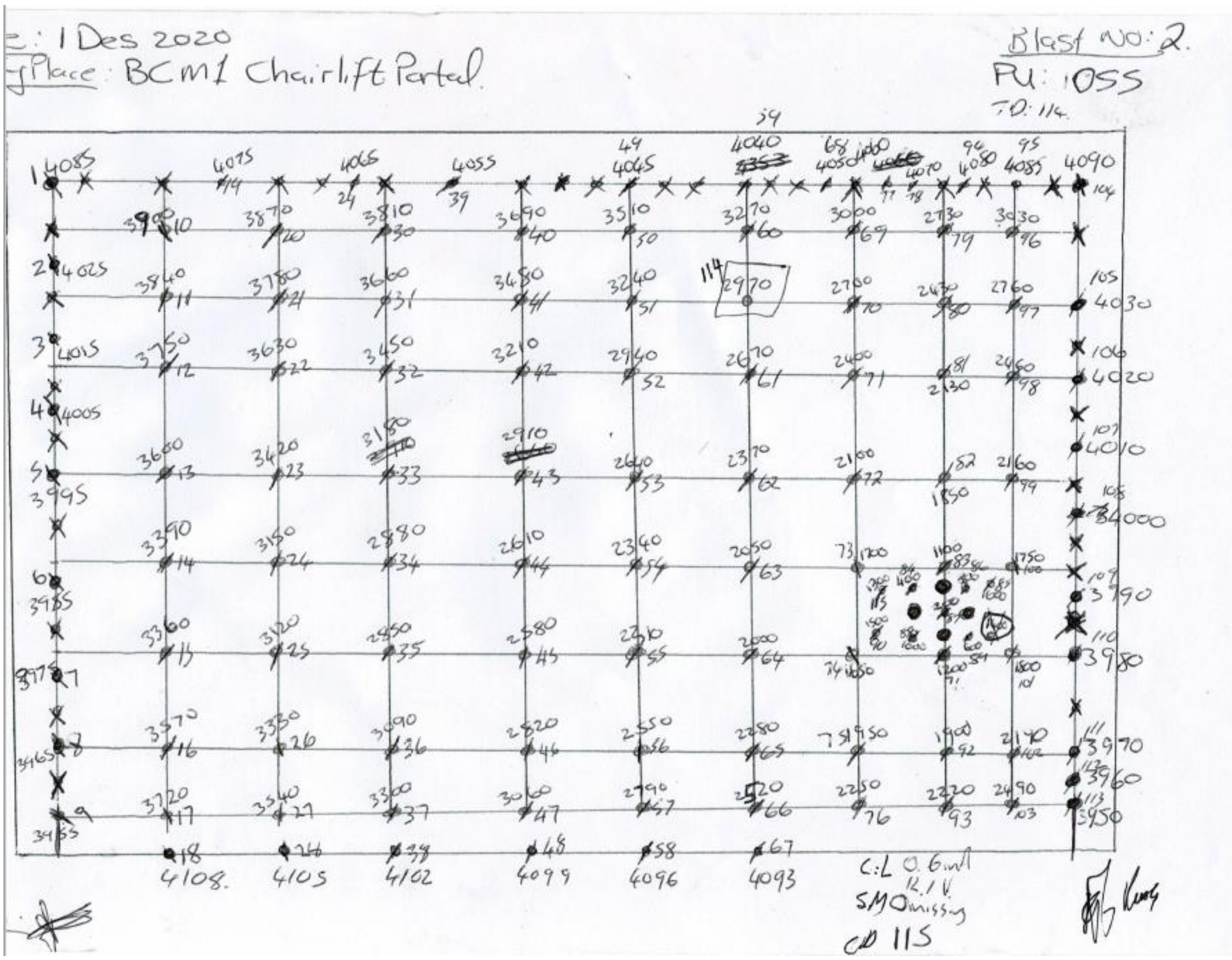
The planned hole length was for a drilled hole of 1.2m, and then to advance +-0.9m. These were however exceeded with the results ranging from 1.2m to 1.4m advance per blast. The Daveytronic Electronic detonator system was used to time and blast each of the 16 blasts.

As per design an average of +-120 holes was charged and blasted as per schedule. Blasting only took place Mondays to Fridays at 16h45, as to allow for the other shafts in the proximity, to first be cleared prior to blasting BCM1. One portal per day was planned. The only day two portals were blasted together was on the 5th of January 2021, after the Christmas break, that stretched from the 15th December to 4 January 2021.

The project was completed in 15 days, as where 30 days was planned.

6.2 **Blast Plans**

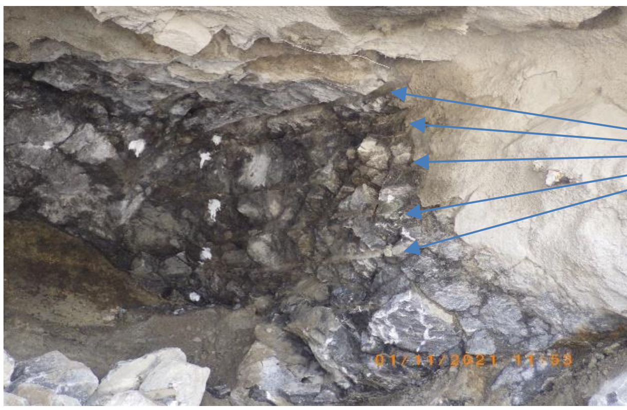
Blast plans were drawn up daily, to assist with the changes in marking and drilling. The timing was then written by hand as to allow timing to be done with the DTSP system as per procedure. Below is a blast plan from the project, written by hand.



Timing of all shot holes was done as per timing on plan, and no out of sequence blasting was encountered during the entire project.

6.3 **Results**

As previously mentioned, the project was completed in half of the planned time frame. This was mainly due to the very competent rock structure encountered, and as such the increase in hole lengths could be adjusted forward. The smooth wall techniques utilized during each blast assisted with creating favourable conditions from the first blast taken, and conditions only improved as the portals advanced with each blast. Below is a picture of the smooth wall blasting results observed.



Barrels can be seen in the picture, showing Smoothwall techniques working

Blasting results included the face advance, fragmentation size and the smooth-wall blasting process. All these results exceeded the planned actions. Below is a picture showing the results after blasting of the muck pile.

The fly rock was kept to a minimum as well with the use of the DTSP system

6.4 VOD tests conducted

Various Velocity of detonation (VOD) tests were carried out during the project. These tests were merely done to check the quality of the explosive product being used. All tests conducted resulted in very good readings, and these readings was within specification from the manufacturer. The tests will be shared separately from this document.

6.5 Seismograph Tests conducted

Nomis Seismographs were also placed in a designated area to check whether the vibration is within acceptable standards, and to measure the difference between shock tube timing and blasting and UGBS timing and blasting. The results will also be shared in a separate document.

6.6 Summary of Project

The project was done in a very professional manner, and all role players involved gave only their best efforts. Due to these efforts the project can be described as a huge success story, and all future similar projects should be based on the findings and lessons learned during this project. The project started as planned and finished ahead of schedule. This milestone alone should be shared and celebrated by all parties involved.

Johan Munnik

Danie Saayman

Enaex Africa

EMTS