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Mass excavation optimization of 603 crusher complex for Grasberg block cave mine

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ABSTRACT

The Grasberg Block Cave mine (GBC) started production in December 2018 and has been rapidly increasing its production milestones since. The GBC's ore handling system includes the 603 Crusher Complex, which was designed and developed to meet 130,000 tonnes per day (tpd) production targets. The 603 Crusher is a unique design that sets itself apart from the previous 601 and 602 crusher complexes. It features a complex design that includes an unloading station, crusher chamber, coarse ore bin, eccentric drive chamber, and conveyor drift with total excavation of 2,851 meter equivalent. This paper outlines the complex aspects of the design, sequencing, QAQC and mass excavation techniques used in the development of the 603 Crusher complex. The construction of the 603 Crusher differs significantly from the 601 and 602 complexes as it exclusively utilizes mechanized mining methods, removing the need for manual handheld techniques. The strategic shift resulted in a significant reduction in development time, completing the project in 15 months as opposed to 24 months for 601/602 complexes. The main driver in this shift was safety to our employees and whilst this project was completed ahead of schedule zero injuries were recorded in this time. This paper highlights the importance of implementing best mining practices improving efficiency and safety in mining operations.

1 INTRODUCTION

PT Freeport Indonesia (PTFI) began the development of the Grasberg Block Cave Mine (GBC) with initial access drifting in 2004, 14 years before the initiation of caving in late 2018 and about 21 years before achieving full production rates of 130,000 to 160,000 t/d of ore by 2025 (Brannon, *et. al*, 2020). The layout of the GBC, with the overlying Grasberg open pit, is shown in Figure 1.

The GBC project, initiated by PTFI in 2004, marked the beginning of an innovative mining project. Fourteen years later, in late 2018, the mine began operations, with expectations to reach full production rates of 130,000 to 160,000 tons of ore per day by 2025.

The Grasberg Mining District, an active hub of underground activity, hosts an array of dynamic underground mining operations, each contributing distinctively to the district's ore production tapestry. Beyond the GBC, the Deep Mill Level Zone (DMLZ) block cave mine sets its sights on 80,000 t/d, while the Big Gossan open stoping operation adds 7,000 t/d to the mix. Meanwhile, the Kucing Liar orebody, currently in the developmental phase, anticipates commencing production in the year 2027.

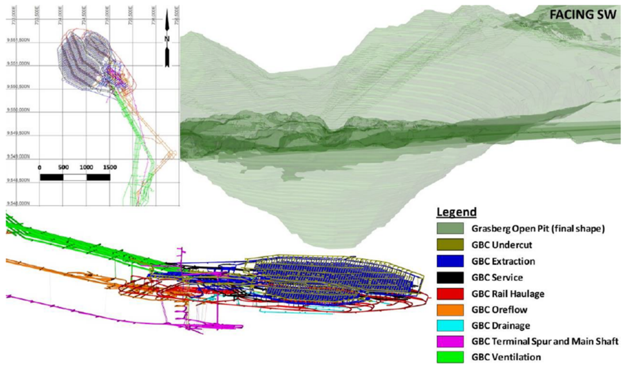


Figure 1 Layout of the GBC and associated infrastructure.

The transition from active pit production in 2019 marked a new chapter in the district's mining history. The Grasberg Open Pit, operational since 1990, set the stage for the district's shift towards underground mining. Figure 2 provides a schematic view of the Grasberg District orebodies. The concentrating plant has a peak capacity of approximately 240,000 t/d. After the conclusion of open-pit mining, peak production targets for the district will remain at 240,000 t/d, sourced entirely from underground operations. The GBC will be the primary source of mill feed, with a target of 130,000 to 160,000 t/d.

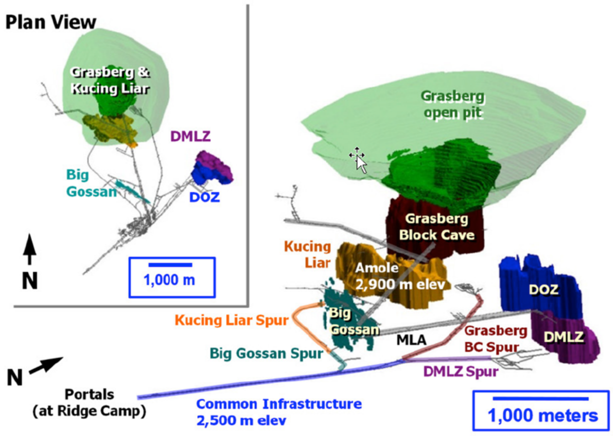


Figure 2 Perspective view of the Grasberg District orebodies and major accesses.

The block caving method is one of the underground mining methods which stands at the highest point of the mass mining method to obtain ore in large quantities and in an efficient time. This method, a masterful exploitation of caving techniques, aims to fracture the ore body under natural stresses, enabling recovery at optimal rates and minimal costs, thereby facilitating the economical extraction of vast deposits through underground mining. The GBC mine, with a mechanized panel caving operation, envisions peak production rates ranging from 130,000 to 160,000 t/d. The proposed mine layout is carefully divided into several production blocks, regulating the caving and production mining rates based on established plans. The extraction levels follow the El Teniente layout, with panel drifts spaced 30 meters apart and drawpoint intervals set at 20 meters. The expansive layout spans a diameter of approximately 1 kilometer (700,000 square meters) and includes nearly 2,400 drawpoints. The El Teniente layout, selected for the GBC, allows for rapid development and forms regularly shaped pillars, ensuring stability at significant depths. Ore extraction involves loaders moving through the extraction level drawpoints, transporting ore to ore passes that lead to chutes located above the haulage level. The ore then travels via rail from the chutes to crushers, passing through the haulage level, which is situated about 40 meters below the ventilation/service level.

2 DESIGN OVERVIEW

The ore flow system at the GBC initiates with the extraction of ore. This ore is first screened through a grizzly, which is equipped with 800mm square openings, to ensure size uniformity. Subsequently, the ore is transported to the underground primary crusher via train. The elevation of the rail haulage level and the rail dump location are fixed, ensuring a streamlined and consistent flow of operations. A train is configured with 11 rail cars, each capable of containing 16m3 of ore, thereby optimizing the load factor to approximately 80% of a $20m^3$ car. Consequently, the total train capacity stands at $176m^3$ or 350 metric tons at nominal bulk density.

The current configuration at the GBC Crushing stations includes two units, each equipped with a 1,400 metric ton (equivalent to 809 m^3) live capacity bin. These bins efficiently receive ore from the rail dump, highlighting the system's design for maximum efficiency. An Apron Feeder, selected for its reliability in extracting ore and controlling the feed rate, delivers the ore to a 63”x89” primary crusher. The crushed ore is then transported to the Millsite via a fairly efficient conveyor system designed for optimal throughput. The proposed integration of Crusher 603 as the third unit in the GBC array is strategically planned to increase the production capacity significantly, from the current capacity to an anticipated 150,000 t/d, with the potential to reach up to 180,000 t/d (to give the average production capability 130,000 t/d to 160,000 t/d in monthly basis, to cover the downday and issue during the month)

The two primary crushers at the Grasberg Block Cave (GBC) mine, characterized by their 63" (1600mm) feed openings, play a pivotal role in the mine's ore processing efficiency. These crushers are designed to handle rocks up to 1,280mm, optimizing the crushing process. The operational efficiency is further enhanced by modifications to the dimension of ore pass grizzly openings, which are directly linked to rock breaker usage. Our observations indicate minimal need for rock breaker intervention, except during preparations for equipment shutdowns.

Significantly, the addition of Mud Rush Sensors and Gates to crushers 601 and 602 represents an advance in managing abrupt ore and mud flow, though challenges in timely mud rush detection and mitigation persist. This highlights an area for potential technological improvement and safety enhancement.

The 603 Crusher Complex, integral to GBC's ore handling system, exemplifies innovative design with its separation into Dry and Wet Side compartments, a strategy enhancing both functionality and safety. The criticality of the wet muck separator design, especially in preventing accidents, cannot be overstated. This underscores the complex's role not only in ore processing efficiency but also in ensuring operational safety.

The detailed structure of the 603 Crusher complex includes the Unloading Station Chamber, Top Crusher Chamber, Ore Bin, Magnet Chamber, BC (Belt Conveyor) 603 Tail Chamber & Conveyor, BC604 Tail, BC605 Head Chamber, Tool Room, Cable Holes, and the Power Control Room & Transformer Room essential for powering the system. Unlike the two preceding crushers, the unique design of the 603 Crusher complex required an extended design process, which led to developmental delays. The development process, initially forecasted to begin in Q4-2020, was instead initiated in Q1-2021.

The final construction design is essential for facilitating excavation processes to accommodate all construction within the underground drift. Once the excavation design process is completed, the design strings is uploaded into the Life Of Mine model and then submitted to the Plan of Intent (POI) for approval through the Deswik MDM (Mine Data Management) approval process. The POI is a subset of the LOM design that has been approved via the approval process. It contains all approved horizontal and vertical development designs. It is issued in PDF and Deswik CAD file format for review and approval by all responsible parties including Geology, Geotech, Ventilation, Survey, Engineering and Operation, ensuring the design can be mined safely and meets production goals. This is formally achieved by each responsible department completing their POI checklist.

3 DEVELOPMENT AND CONSTRUCTION

The development of the 603 Crusher Complex, distinguished by its dual-sided design, spanned an impressive 15 months, beginning in March 2021 and concluding in May 2022, covering a total development distance of 2,851 mDEQ. This ambitious project involved numerous stakeholders, including Redpath, RUCCI, Alimak, Raisebore, Redpath Solo, PTFI Hauling, and QC. Adhering to strict safety protocols, the project achieved excellent safety records, with zero accidents reported throughout the accelerated timeline.

The developmental process of the entire complex itself represents a monumental excavation effort, with a total excavation distance of 2,318 meter Linear or equivalent to 2,851 meter Deq. This extensive undertaking, spanning 16 months from February 2021 to May 2022, involved rigorous sequencing to ensure the precise execution of each phase. Notably, given the unidirectional nature of the development process, any omissions or errors in a sequence necessitated careful rectification, underscoring the importance of thorough planning and execution.

The scale of the complex is truly imposing, with a total height of 54m and a direct connection featuring dimensions of 11mx20m from the Unloading Station Chamber at 2760/ Haulage

Level to the Apron Feeder Chamber (see figure 6 for detail).

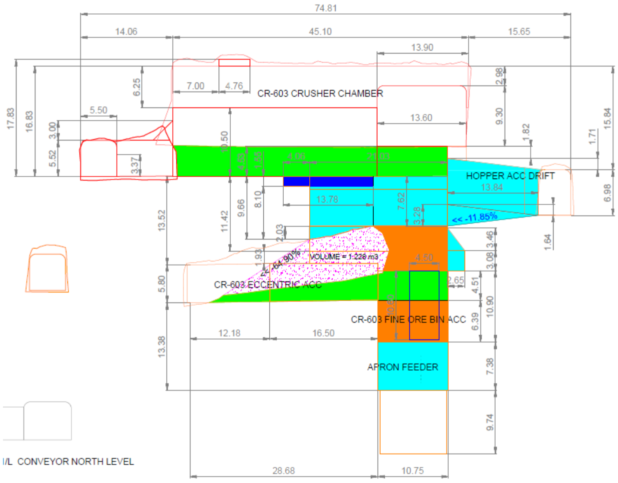


Figure 3 Crusher 603 Top Part Complex.

To provide perspective, as shown in Figure 3, this complex is nearly twice the size of the Kiruna Town Hall building. Additionally, the project involved two massive blasts with excavation dimensions of 11m x 10m x 11m and 6m x 10m x 10m, respectively, highlighting the scale of the undertaking.

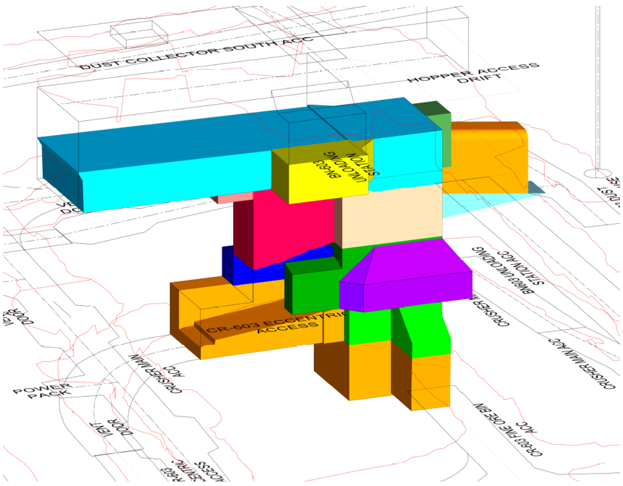


Figure 4 Crusher 603 Top Part Complex.

The magnitude of this development also necessitated the installation of a massive array of ground support systems throughout the complex to ensure its structural integrity over the anticipated 20-year lifespan. This comprehensive ground support system comprises paddle bolts, MDX bolts, Cable bolts, and Shotcrete, augmented by Safety Layer mesh installations across all chambers to safeguard personnel engaged in regular operations, maintenance, and repair activities over the mine's lifespan. The recorded statistics reveal the magnitude of this effort, with 102,763 m of Cablebolt installed and 8,466 CuM of Shotcrete sprayed throughout the complex.

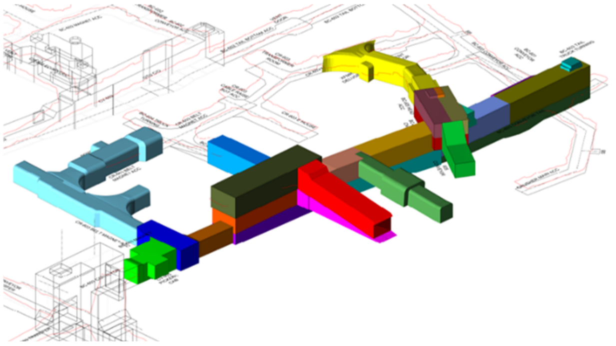


Figure 5 Crusher 603 Bottom Part Complex

The critical path of the development cycle encompasses various of elements and associated equipment, including drilling, loading and blasting, mucking, mechanical scaling, primary ground support, haulage, and services and utilities, are each very well coordinated to ensure seamless progress and adherence to project timelines.

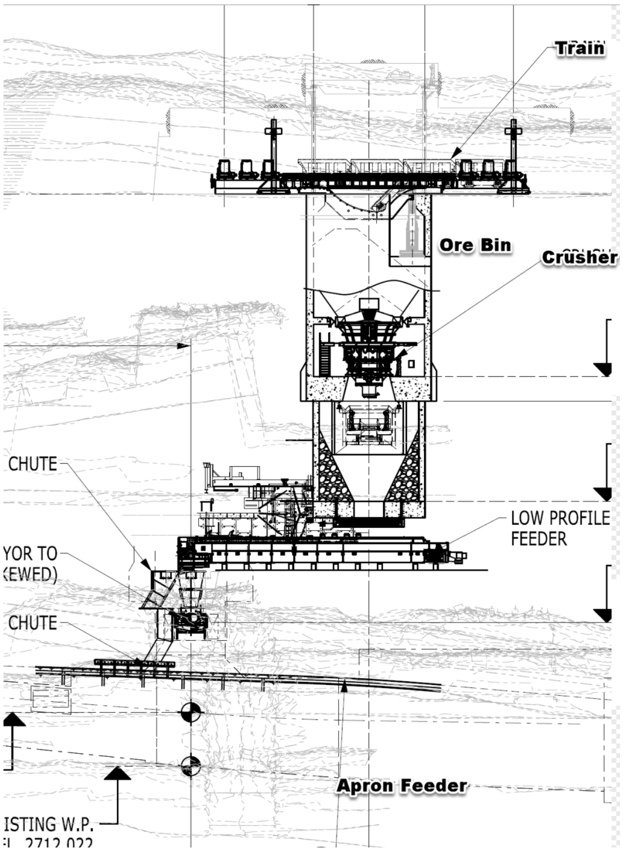


Figure 6 Construction View of CR603.

Beyond the excavation and ground support installation, the installation of accessories assumes paramount importance, with 238 Backplate installations, 261 wall plate installations, and 784 rock anchor installations which required for the construction process, completed in each sequence from top to bottom. This approach is complemented by the installation of Geotech monitoring systems to track ground movements throughout the facility's lifespan, encompassing the installation of 43 extensometers and 5 smart cables.

The handover process from the development team to the construction team marks a crucial phase, necessitating precise attention to detail and thorough documentation to ensure the excavation's integrity and compliance with construction requirements. The submission of documentation via the MDM Deswik process undergoes rigorous validation and approval processes before being transmitted to the construction team, ensuring adherence to specifications and regulatory standards.

In addition to its expansive dimensions and strategic location, the Unloading Station Chamber boasts robust ground support systems designed to enhance structural integrity and ensure long-term stability. The installation process entails the implementation of extensive measures, starting with the deployment of 5.6 weld mesh and 3m resin bars, strategically spaced at intervals of 1.2m x 1.2m to provide primary support. This initial phase is followed by the installation of 7m well tensioned cable bolts, positioned at the rear of the chamber with a spacing of 1.0m x 1.0m, extending to within 0.5m from the floor. The subsequent application of 75mm fibercrete further reinforces the chamber's structural framework, culminating in the final installation of a safety layer mesh. These comprehensive ground support measures not only enhance the chamber's structural integrity but also mitigate potential safety risks, ensuring a secure working environment for personnel involved in ongoing operations.

Furthermore, the phased development approach implemented in the construction of the Unloading Station Chamber underscores the project's emphasis on detailed planning and execution. Each stage of the development process, from initial excavation to final benching, is executed precisely and attention to detail, guided by comprehensive safety protocols and engineering standards. Prior to the commencement of secondary support activities, a thorough i-site scan survey is conducted to identify any potential hazards or structural irregularities within the chamber. This proactive approach enables the project team to address any emerging challenges promptly, ensuring the seamless progression of construction activities while prioritizing the safety and well-being of personnel.

3.2 CR603 Crusher Chamber

Directly below the Unloading Station Chamber lies the Crusher chamber, positioned at an elevation of 2,730 m AMSL, designated for the gyratory crusher to process ore material to the desired specifications. Spanning 45m in length and featuring dimensions of 12.3mWx16.8mH, this chamber underwent a sequential excavation process across four phases, thoroughly coordinated to ensure optimal ground support, accessory installations, and Geotech monitoring in each sequence. Sequential excavation process start with excavation of First pass with dimension 7mWx7mH, continued with slashing of Top part with dimension slashing 5.3mWx7mH, followed with 5m benching down for 12.3mW dimension and finish with last part benching 4.8m down with same width for 12.3mW (see Figure 7 for Crusher Chamber sequence)

The ground support installed in this chamber is substantial, beginning with 5.6 weld mesh and 3m resin bars spaced at 1.2m x 1.2m intervals for primary support. This primary support is then augmented by 8m well-tensioned cable bolts, spaced at 1.0m x 1.0m intervals, extending from the back to within 0.5m from the floor. Following the cable bolts, a layer of 75mm fibercrete is sprayed onto the surface, providing additional reinforcement. The installation process culminates with the placement of a safety layer mesh, ensuring comprehensive structural integrity and enhancing safety standards within the chamber.

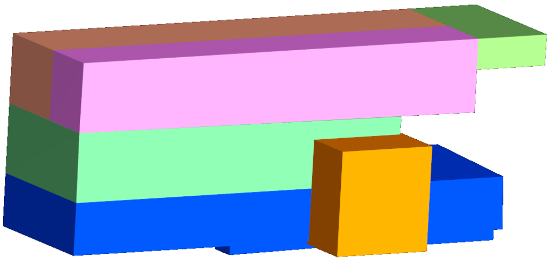


Figure 7 Crusher Chamber Excavation Sequence

3.3 Ore Bin & Pocket Chamber

The Ore Bin and Pocket Chamber serve as pivotal components. The Ore Bin stores the material from train, accommodating 1.5 times the train's capacity before it goes to Crusher while the pocket chamber function provides foundation for the crusher. The excavation process for this chamber, spanning dimensions of 11mWx8.4mH and 21m in length, represents a complex endeavor involving both horizontal and vertical excavation methods, executed to optimize efficiency and minimize project timeline.

The development process of this chamber was quite intricate, employing two methods of excavation: lateral development using a Jumbo and vertical development using Raisebore, followed by a drop raise with Solo's holes to excavate the entire chamber. The excavation process was divided into five sequences. It begins with two sequences at the top part using a Jumbo to excavate the first pass with dimensions of 7mWx6mH, followed by slashing for 4mWx6mH. Next, 1m diameter Raisebore drilling creates void for widening blasting free face using the drop raise method. Finally slashing is completed to achieve the full width dimension.

The application of the drop raise method allowed for the excavation of a 11mx10mx11m dimension with one blast, significantly saving time compared to regular horizontal excavation. The drop raise excavation began with Raisebore drilling to create a 1m diameter opening, utilized as free space for the blasting process, followed by drilling 89mm vertical blast holes with Solo along an 11m x11m span (see Figure 8 for Drill and Blast Pattern for vertical excavation)

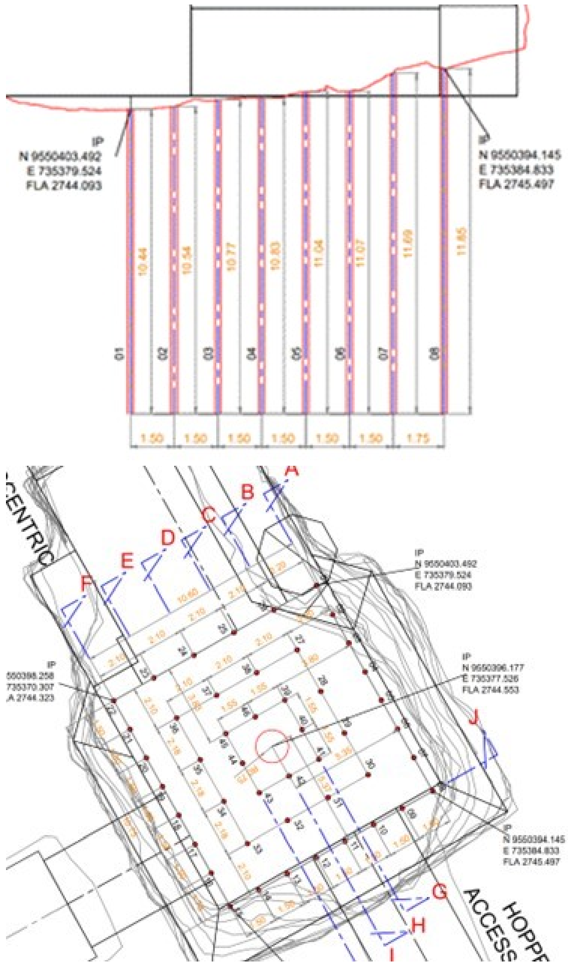


Figure 8 Ore Bin and Pocket Vertical Blast Pattern.

The ground support installation in this chamber was quite complex due to its intricate shape. It commenced with 8mm weld mesh and 3m resin bars spaced at 1.2mx1.2m intervals for primary support. This primary support was then reinforced by 6m well-tensioned cable bolts spaced at 1.0mx1.0m intervals, both at the back and 0.5m from the floor. Additionally, at the brow, there were additional 6m fully grouted and well-tensioned cable bolts with a 45-degree inclination. At the top part of the brow, there were further additions of 4m fully grouted 32mm threadbars installed. Following the installation of ground support, a layer of 75mm fibercrete was sprayed onto the surface, providing additional reinforcement. The installation process was finalized with the placement of a safety layer mesh, ensuring comprehensive structural integrity and enhancing safety standards within the chamber.

Apron Feeder Chamber

The feeder chamber in CR-603 is below the crusher unlike 601 and 602 where it is above. In CR-603 we have a low profile feeder, which is a hybrid between a traditional apron feeder, and a belt conveyor, this way it could handle and transport the wet ore very well.

The excavation of the Apron Feeder chamber, featuring dimensions of 10.75mWx17mH and extending along a length of 38m, presents unique challenges necessitating a phased approach to ensure efficient excavation and structural integrity. This chamber, critical to the ore handling system, undergoes meticulous planning and execution to facilitate unified integration with downstream processes and equipment.

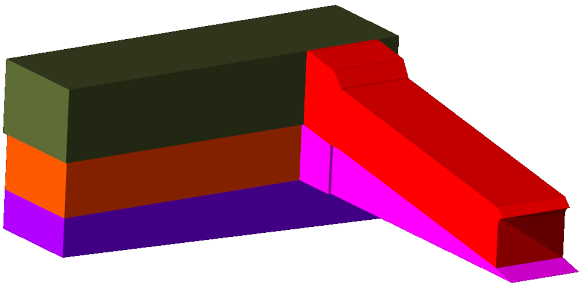


Figure 9 Sequence Apron Feeder.

Ground Support installed in this chamber is also massive, beginning with the installation of 8mm weld mesh and 3m resin bars spaced at 1.2mx1.2m intervals for primary support. This primary support is then reinforced with 8m well-tensioned cable bolts spaced at 1.0mx1.0m intervals, extending from the back to 0.5m from the floor (see Figure 9 for Apron Feeder Chamber excavation sequence). Following this, a layer of 75mm fibercrete is sprayed onto the surfaces, providing additional reinforcement. The installation process is finalized with the placement of a safety layer mesh, ensuring comprehensive ground stability and enhancing safety standards within the chamber.

The sequencing and scheduling process underwent significant improvements in the apron feeder excavation, resulting in a five-week optimization compared to the original schedule. Instead of waiting for the sequence from the top side to begin the apron feeder excavation, optimization efforts-initiated development on the apron feeder earlier and in parallel with the excavation above.

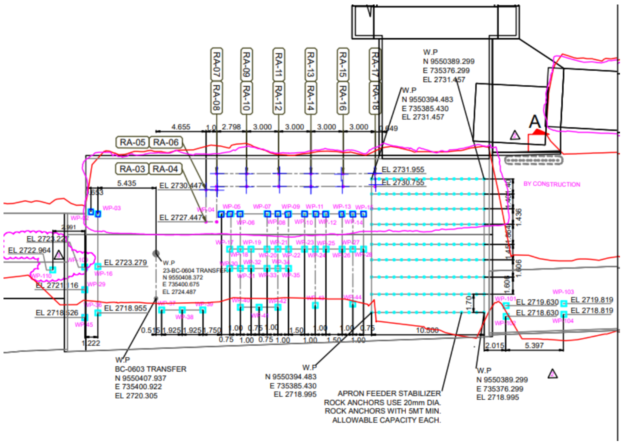


Figure 10 Construction Accessories at Apron Feeder Chamber

Excavation activities focused on the apron feeder, leaving proper pillars between the levels above and the chamber. The process continued until the bottom part of the apron feeder chamber was reached, followed by secondary ground support and accessory installation. Subsequently, the chamber was refilled with muck to create a ramp with the proper gradient for equipment access after completing the sequence on the Top Level.

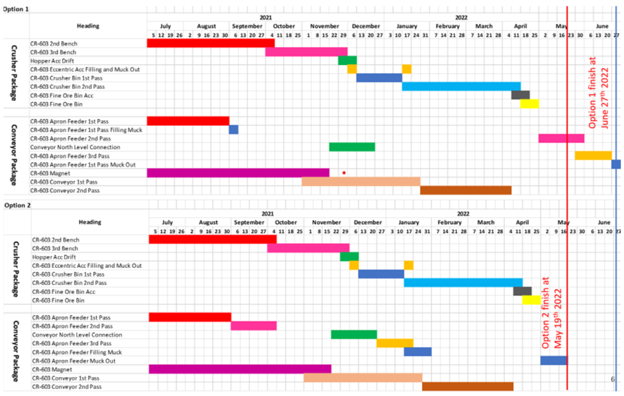


Figure 11 Optimization of Apron Feeder Sequence & Method.

Executing this process posed several challenges, including ensuring safety during operations, facilitating a smooth and swift muck refilling process, and expediting equipment delivery to accelerate the overall process. Moreover, sourcing muck for refilling the chamber proved to be another logistical challenge, necessitating the identification of the nearest available sources to expedite operations.

The schedule simulation below illustrates the comparison between the original plan and the optimization schedule achieved through early excavation of the chamber and muck refilling.

4 DELAY AND EXCAVATION SEQUENCE

The project encountered a delayed start in excavation, primarily attributed to issues with design readiness and the continued utilization of the CR603 unloading access for CR602 construction purposes. Originally slated for development initiation in Q4-2020, the project's actual commencement occurred in Q1-2022, resulting in an unexpected setback. However, proactive measures were swiftly implemented to address these challenges and optimize the excavation sequence. Despite the initial delays, the project team successfully reduced the total development duration from the initially projected 17 months to a more efficient 15 months (see Table 1 as reference detail), showcasing adaptability and make rapid changes to exceed targets set at the beginning.

Moreover, the development and construction of the 603 Crusher Complex demanded detailed attention to sequencing, quality assurance and control (QAQC), and mass excavation techniques. While encountering initial setbacks, strategic improvements in excavation sequencing were instrumental in streamlining the development process, enhancing efficiency, and expediting project timelines.

To mitigate further delays and ensure project alignment with established timelines, a series of proactive measures were implemented. Regular design discussions through Plan of Intent (POI) meetings between the Phoenix Head Office and site personnel facilitated the resolution of design-related issues and promoted alignment on project objectives. Additionally, bi-weekly meetings between engineering, operations, and geotechnical teams provided a platform to discuss project updates, address emerging issues, and recalibrate timelines as necessary.

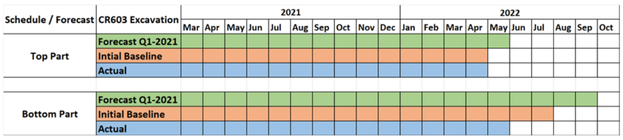
The detailed sequencing process plays a critical role in optimizing the schedule and executing excavations for each sequence efficiently based on available resources. It involves dividing the excavation process sequence by sequence, considering the capabilities and coverage of drilling machines, as well as ground support installation equipment such as Cabolter and Maxijet sprayers for shotcrete.

In addition to the geotechnical limitations, which restrict the development of the first pass excavation dimension to no more than 7mWx7mH, the choice of drilling machines for excavation and primary support installation, namely the Axera7 and Axera8, is crucial. Selecting the right equipment for each sequence ensures that our coverage ability to reach is not limited. The use of Cabolter and Maxijet sprayers for secondary support installation also presents constraints. However, it provides flexibility in the benching process, allowing us to pursue higher profiles. This adaptability enhances our approach to benching, contributing to the overall efficiency of the excavation process.

Distinguishing itself from Crusher 601 and 602, which relied on a combination of mechanized and manual handheld excavation methods, the 603 Crusher Complex prioritized mechanized excavation techniques to optimize efficiency and safety. By strategically designing access points to accommodate mechanized equipment, particularly jumbo and cabolter machinery, the project minimized reliance on manual excavation methods, mitigating safety risks and safeguarding against potential delays.

In summary, the successful development and construction of the 603 Crusher Complex underscore the resilience, adaptability, and collaborative spirit of the project team. Through proactive problem-solving, thorough planning, and effective communication, the project overcame initial challenges and achieved its objectives within a condensed timeframe. Moving forward, the lessons learned from this endeavor will serve as valuable insights for future projects, informing best practices and driving continuous improvement in mining operations and infrastructure development.

Table 1 CR603 Forecast vs Baseline Schedule vs Actual Duration.



5 SAFETY AND OPTIMIZATION

The strategic decision to fully mechanize the development of CR603, moving away from traditional Alimak excavation and ground support installation techniques in some areas that rely on handheld methods, marked a significant commitment to enhancing safety standards. The project's deployment of advanced mechanized methods, including the use of Jumbo drills and Solo rigs for excavation and a suite of mechanical tools for ground support, played a pivotal role in achieving an exemplary safety record, culminating in zero work accidents. This achievement highlights the effectiveness of mechanical methodologies over traditional practices in ensuring worker safety.

The adoption of mechanized approaches not only ensured enhanced safety but also facilitated the expeditious completion of project 603 Crusher Complex, surpassing the target schedule by a notable margin of 2 months. This achievement underscores the efficacy of high safety standards coupled with robust communication frameworks among the myriad groups involved in the project. Effective supervision across all phases of the project, coupled with the implementation of Job Safety Analysis (JSA) for each new task, served as foundational pillars in ensuring adherence to safety protocols and mitigating potential risks.

The use of fully mechanized permanent ground support installation such as Cabolter and Maxijet sprayers also presents constraints. However, it provides flexibility in the benching process, allowing us to pursue higher profiles. This adaptability enhances our approach to benching, contributing to the overall efficiency of the excavation process. The adoption of mechanized approaches not only ensured enhanced safety but also facilitated the expeditious completion of Project 603, surpassing the target schedule by a notable margin of 2 months.

Furthermore, the deployment of strategic measures such as the implementation of barricades and delineation of spacing between equipment operating in adjacent areas exemplified proactive risk management practices. The detailed identification and control of hazards, particularly in scenarios involving concurrent work activities at varying elevations, underscored the project's commitment to ensuring the safety and well-being of all personnel involved.

Moreover, the success of Project 603 serves as a testament to the efficacy of mechanized methodologies in fostering a culture of safety and efficiency in large-scale industrial endeavors. By prioritizing safety at every stage of the project lifecycle, from planning and execution to monitoring and evaluation, Project 603 not only achieved its objectives ahead of schedule but also set a benchmark for excellence in safety and project management practices.

Various improvement initiatives have been undertaken to enhance the set schedule. These efforts include rigorous control measures and reports by survey team. Additionally, there has been a re-sequencing and adoption of updated excavation methods in critical areas like the apron feeder chamber as described above, aimed at shortening the project duration. Moreover, specific areas have undergone partial handover processes, enabling the construction team to commence work sooner.

Ensuring that all actual excavations meet the design, which is controlled by the survey team, is also one of the crucial things for maintaining the smooth progress of the process and avoiding any need for rework, which could cause delays and additional time. Any tight to the design found during the excavation process discovered later necessitates rework to address, resulting in delays due to the subsequent ground support. Additionally, overbreaks can have significant impacts from both geotechnical and construction perspectives, potentially requiring additional ground support to stabilize the area until the end of the mine's life, as well as extra construction materials such as rock anchors and concrete.

As part of this process, the survey team conducts control surveys during each round of development, identifying any tight areas following blasting. These areas can then be addressed directly through scaling or re-blasting before proceeding to the next round. Concurrently, the survey team sends reports detailing any tightness and overbreak found via email to notify the operation team. This process is critical in ensuring that all excavations meet construction requirements and do not pose construction issues before secondary support is installed and the process continues to the next sequence or level.

Furthermore, partial handover discussions between operation, engineering, and construction teams enabled the commencement of construction activities in areas not accessed or utilized by operational functions. During the process we did partial handover earlier than schedule on these areas : Top Crusher Chamber, Electrical-House and Transformer Chamber and Crusher Pocket. This phased approach to handover maximized resource utilization and minimized disruptions to ongoing operations, thereby fostering a cohesive and efficient project environment.

The collaborative efforts of various stakeholders, including project managers, engineers, supervisors, and frontline workers, were instrumental in realizing the project's overarching goals while upholding the highest standards of safety and professionalism. Moving forward, the success from Project 603 will continue to inform and inspire future endeavors, guiding the way towards the realization of safer, more efficient, and sustainable industrial practices.

6 CONCLUSION

In conclusion, the development of the Grasberg Block Cave mine (GBC) and its integral component, the 603 Crusher Complex, represents a significant milestone in the realm of mining operations especially in underground mines operated at PT. Freeport Indonesia. The inception of the GBC in December 2018 marked the beginning of a transformative journey characterized by rapid production escalation and innovative ore handling systems. Designed to meet ambitious production targets of 160,000 t/d, the 603 Crusher Complex embodies cutting-edge design principles and mechanized mining methodologies.

Figure 12 Crusher Chamber Construction

The construction of the 603 Crusher Complex deviated from traditional approaches as was carried out in the excavation process at the Crusher 601 and Crusher 602 complexes, opting for fully mechanical development devoid of Alimak for excavation or ground support installation. This strategic shift towards mechanization not only expedited project timelines, culminating in completion 2 months ahead of schedule, but also underscored a steadfast commitment to elevated safety standards. Throughout the project's accelerated timeline, zero work accidents were recorded, a testament to meticulous planning, robust supervision, and stringent adherence to safety protocols.

The successful realization of the 603 Crusher Complex underscores the paramount importance of implementing best mining practices to improve efficiency and safety in mining operations. By leveraging mechanized methodologies, fostering effective communication among stakeholders, and prioritizing safety at every stage, mining endeavors can achieve unprecedented levels of productivity and operational excellence.

As mining operations continue to advance, the insights gained from the development of the 603 Crusher Complex will act as a valuable reference, guiding future projects and inspiring innovation in large-scale underground excavation at PT Freeport Indonesia. By maintaining a strong commitment to safety, efficiency, and technological progress, mining enterprises can overcome challenges, explore new opportunities, and expand the limits of what is possible in the pursuit of sustainable resource extraction.

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