

Partial Extraction of Local Support Pillars in the 106 S4 Region of Cooke 3 Shaft, Harmony's Randfontein Operation: A Case Study

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ABSTRACT

The presence of five reef bands of the Upper Elsburgs (UE A1 – A5) has led to multiple reef band extraction in the 106 S4 area of Cooke 3 shaft, Harmony's Randfontein operations. Before extracting the 4m wide A5 reef, the A2 reef below it was mined conventionally at a stoping width of 1.2m. Thereafter the now partially distressed A5 reef was mined with an average middling of 17m separating the two reefs. While the A2 reef was supported with packs and crush pillars, a bord and pillar mining method was used on the A5 reef with 10m wide roadways and 12m x 8m pillars spaced 8m apart on strike, giving an extraction ratio of 76%. The A2 reef was mined out in 1988 and the first phase of A5 reef in 1993. Although backfill was widely used on the mine at that time, none was placed on either of the two reefs in the 106 S4 pillar region.

During 2006 a feasibility study was conducted to determine whether partial extraction of the remaining A5 pillars was possible. This resulted in a second phase of mining in the area. Rock engineering was involved in formulating and implementing strategies to reduce the risk of pillar failure, foundation failure, falls of ground and potential massive collapses. This paper tracks the progress of the mining operations in the area and describes the implementation of these strategies.

INTRODUCTION

Cooke 3 shaft was sunk in 1982 and commissioned in 1985 as part of JCI's Randfontein Estates Gold Mining operations. The shaft is located 20 km South of Randfontein and 5 km East of Westonaria on the North West portion of the Witwatersrand system. A location map is presented in Figure 1.

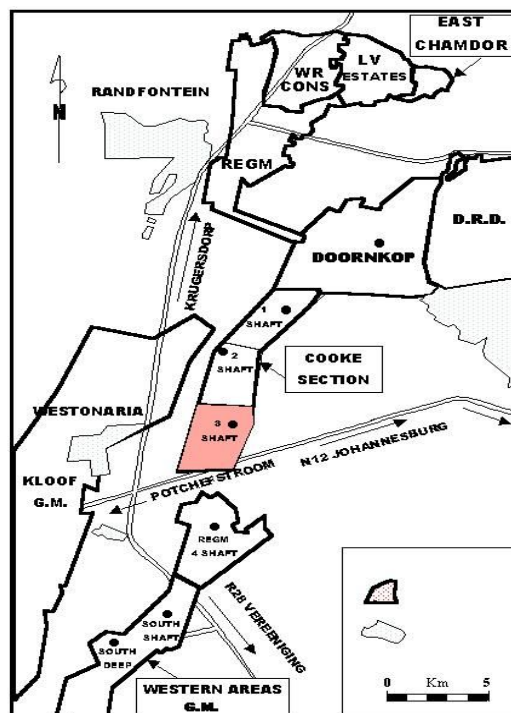


Figure 1. Location of Cooke 3 shaft

The shaft was originally designed to accommodate mechanised mining operations. At the peak of production in the early 1990's the shaft managed to achieve a record of 250 kt hoisted in a single month. Current mining is taking place on a scattered basis by conventional, semi-trackless and full trackless methods. At present approximately 10% of gold production is sourced from vamping of trackless roadways and stopes. Current reef horizons being exploited are the Upper Elsburgs (UE), the Kimberley 4 (K4) and the Ventersdorp Contact Reef (VCR).

Pillar reclamation forms a significant portion of the Life of Mine plan. In the past enormous quantities of ore were extracted by bord and pillar methods with most of these bords later being backfilled. The pillars left behind still contain significant amounts of gold. These are being extracted as part of current mining operations. From a strategic point of view it is imperative that these pillars be extracted in such a way that the effect on the overall stability of large areas is minimised.

FEASIBILITY STUDY

A feasibility study into mining the S4 pillars was conducted in 2006 by among others, experienced production personnel, environmental and grade control officers and a Rock Engineer. The observations listed below were made by the Rock Engineer following his initial examination of the area:

- 106 level is 850m below surface with low virgin stress conditions and a k-ratio of 1.
- The regional geology around Cooke 3 appears to afford adequate regional stability with the result that seismicity was not a major concern, however, with increased remnant extraction, seismicity might increase.
- On the local scale, support and mining sequences must be designed such that access ways are kept stable for as long as they are required to remain serviceable.
- The pillars should therefore be extracted on a retreat basis, completely abandoning the areas where pillar reclamation has taken place.
- No backfill had been placed on either the A5 or A2 reefs mined out in this area; however the surrounding bord and pillar mining areas were extensively backfilled.

Access Roadway

- The access roadway was originally supported with 25mm diameter x 2.4m pre-tensioned resin grouted rebars on a 1m x 1m square pattern with mesh and lace in places where conditions required it.
- The access roadway was serviceable; however in places the height of the roadway exceeded 7m, and required costly and time consuming re-supporting.
- Where the roadway passed through a fault loss abutment, the roadway sidewalls appeared to be highly stressed with sidewall spalling. In addition to the rebar, 4.5m x 20t cable anchors were installed in the hangingwall on a 2m diamond pattern.

Figure 2 shows mesh and lace installed in a portion of the access roadway when it was originally developed.



Figure 2. Mesh and lace used in parts of the access roadway

S4 Pillar Region

- As with the access roadway, the pillar roadways were supported with 25mm diameter by 2.4m pre-tensioned resin grouted rebar on a 1m x 1m square pattern.
- The condition of the hangingwall above the 10m wide roadways and 8m wide holings was generally very good; however some steeply dipping joint sets were observed both parallel to and at right angles to the orientation of the roadways.
- All the pillars appeared to be in a stable condition with no evidence of scaling.
- Originally the extraction ratio was 76% with average pillar dimensions of 10m x 8m. The proposed extraction plan would increase the ratio to 82%.
- Two massive falls of ground were found, one in the north portion near a fault loss, and the other on the south side of the operation. The thickness of the fallout reached 3m in places, exceeding the length of the roofbolt support.
- In the up-dip south west side of the excavation, roof bolts were found protruding through the footwall as shown in Figure 3. These roofbolts indicated a middling of less than 2m between the A5 and the mined out A2 reef below it. Some subsidence was also evident in the A5 footwall. Due to the narrow middling, it was decided not to mine these south west pillars.

Figure 3. Roofbolts protruding through

Figure 4 shows a plan view of the S4 as follows:

- Roadway spans
- Holings
- Stopping width
- Pillar dimensions
- Dip
- Area shown

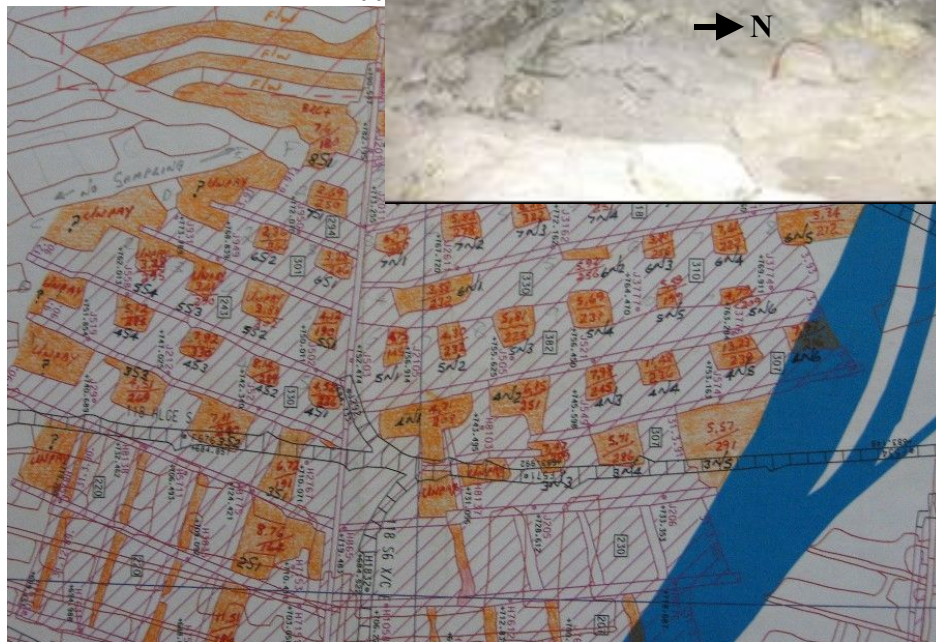


Figure 4. S4 Pillars on the A5 reef before phase 2 mining

The pre-extracted A2 reef which lies directly below the S4 pillars is shown in Figure 5. The middling between the two reefs is, on average 17m varying from only 2m on the south west side to more than 30m in the east. The outline of the initial A5 roadway development is indicated in red.

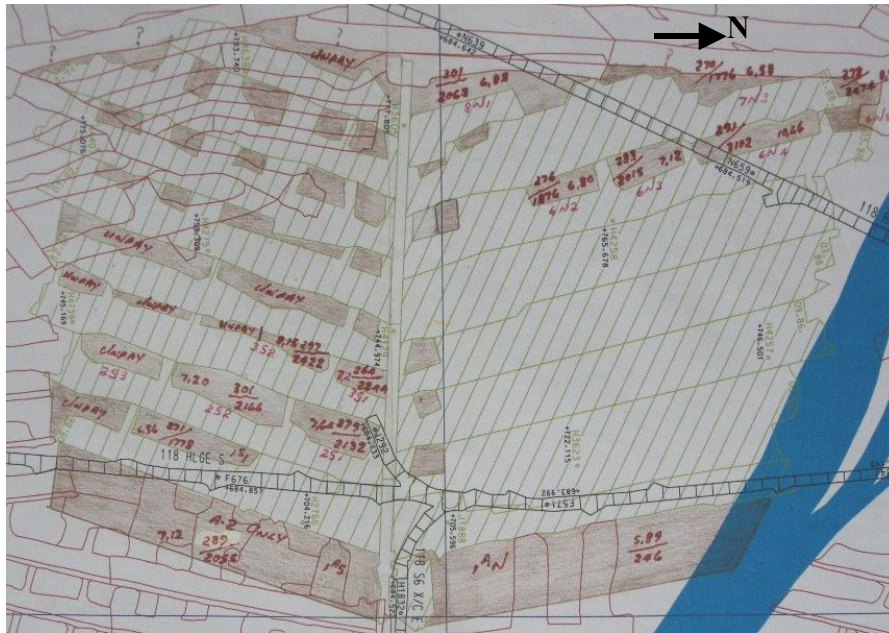


Figure 5. The A2 reef below the A5s. Crush pillars left on the A2 reef are shown

A composite plan, showing the two reefs superimposed is presented in a box in Figure 6. The scattered mining in the surrounding area is also shown.

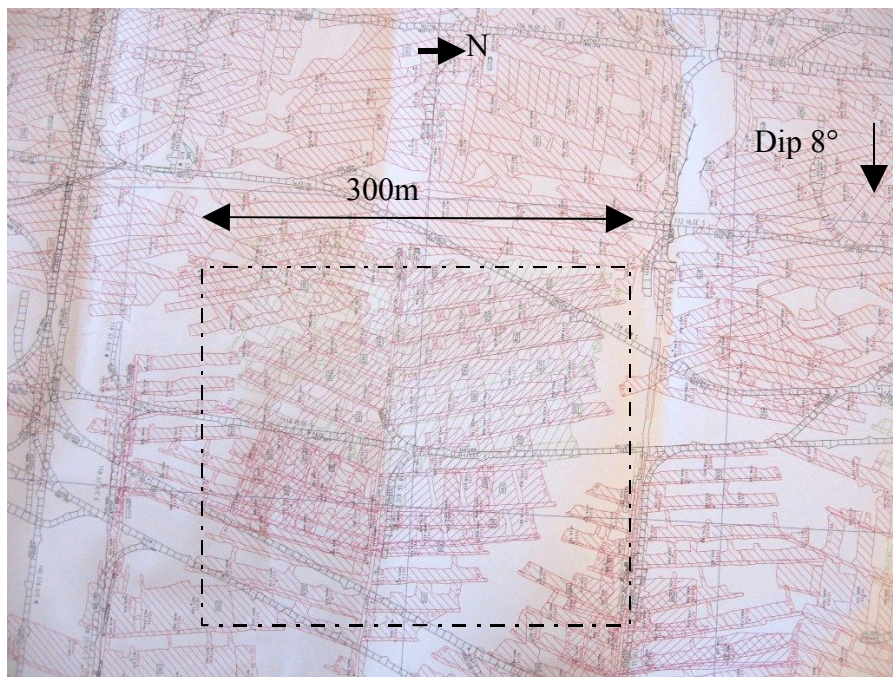


Figure 6. A Composite plan of the A2 and A5 reefs and the surrounding areas

A Cross sectional view showing the dimensions of the pillar mining area is presented in Figure 7. The hangingwall and footwall of the A5 consists of massive competent quartzites. Laboratory testing has indicated a UCS of between 240 MPa and 310 MPa for both the A5 reef and the hangingwall rock.

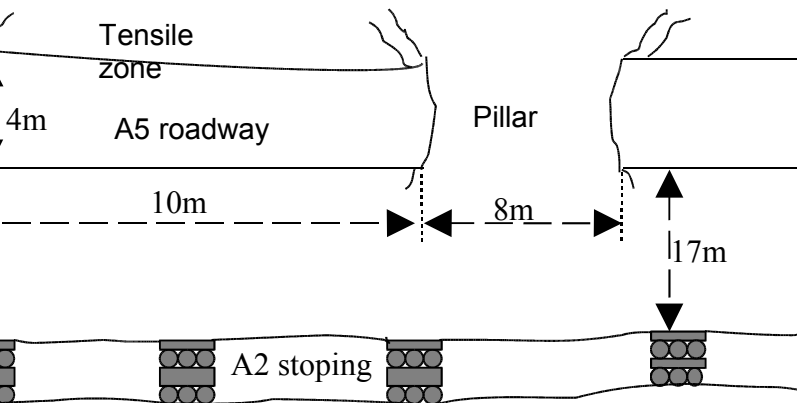


Figure 7. Roadway, pillar and middling dimensions

NUMERICAL MODELING

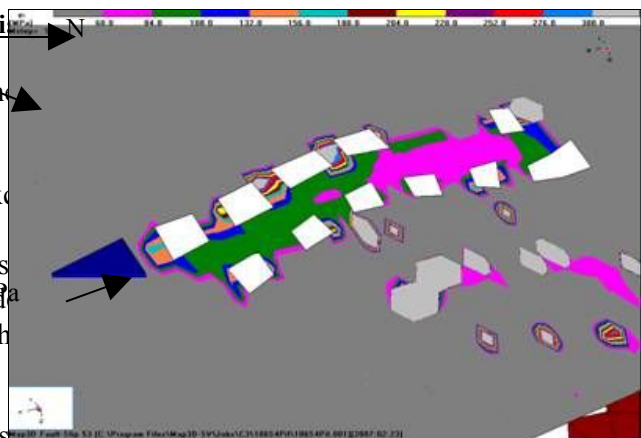
As part of the feasibility study a numerical model was built using Map3D which mimicked the extraction sequence and the subsequent stress changes in the neighboring pillars and the roadways hangingwall. The model used a UCS of 270 MPa for both the pillars and the hangingwall and a k-ratio of 1. Sequential modeling steps showed changing stress patterns in the pillars as they were extracted using a retreat mining method, i.e. extraction from the South towards the North.

Figure 8 shows the state of stress in the roadway pillars prior to any mining. The model shows that the pillars on the West side of the roadway were already subjected to loads of more than 300 MPa. Also shown in Figure 8 is the state of stress in the remnant pillars on the down-dip east side of the roadway. The blank areas indicate mined out portions.

Figure 8. State of stress in the pillars and immediate hangingwall

Following analysis of the numerical model, the following were made:

- The pillars on the west side of the roadway have failed.
- Sequential mining of the pillars shows that all their UCS values will be exceeded.
- A further physical examination of each pillar to assess the following:
 - The condition of the pillar
 - The presence of discontinuities
 - Cracks in the hangingwall and footwall next to each pillar, indicating possible pillar punching
- The pillars should be only partially extracted. Complete extraction of the pillar might result in failure of the crown above the pillar.
- The final dimension of the pillar should not be less than 4m by 6m on plan.
- The pillars should be extracted on a retreat basis from the South to the North with the Southern most pillar left intact.
- Not every pillar should be mined, at-least every third pillar should be left intact to create a barrier against regional collapse.



- The area should be treated as a special area, and special area precautions applied at all times.
- The type of explosives used should cause minimal damage to the hangingwall.
- Pre-conditioning should be applied to all pillars where more than one blast will be taken.
- A mechanical scaler should be used to prepare the face of each pillar prior to the commencement of drilling operations as they may be highly stressed.
- Netting should be placed against the pillars prior to drilling to protect the drilling crews from spitting rock.
- Cleaning and vamping should be kept up to date, minimizing the time exposure of men and machinery to potentially unstable ground conditions.

MINING METHOD

Upon completion of a grade evaluation of the relevant pillars and the numerical modeling, an extraction sequence was planned. It was decided that two crews would simultaneously begin mining in the lower south side of the region furthest from the entrance, and that mining would then continue northwards along the lower line of pillars, before progressing to the next line and then continuing in the same sequence. According to recommendations, at-least every third pillar was to be left un-mined. While hand-held drilling equipment would be used for face preparation, trackless equipment would be used for cleaning operations. Because of the approximately 500m haul distance to the tipping area it was unlikely that cleaning would keep pace with mining, however mining operations were to continue at full pace to reduce human exposure in the area as soon as possible.

The mining method used, entailed extracting the centre third of the pillar from the down dip side and then cutting 2m off the up-dip side of the pillar as shown in Figure 9. A low V.O.D. explosive was used to reduce hangingwall damage and special areas precautions were enforced at all times.

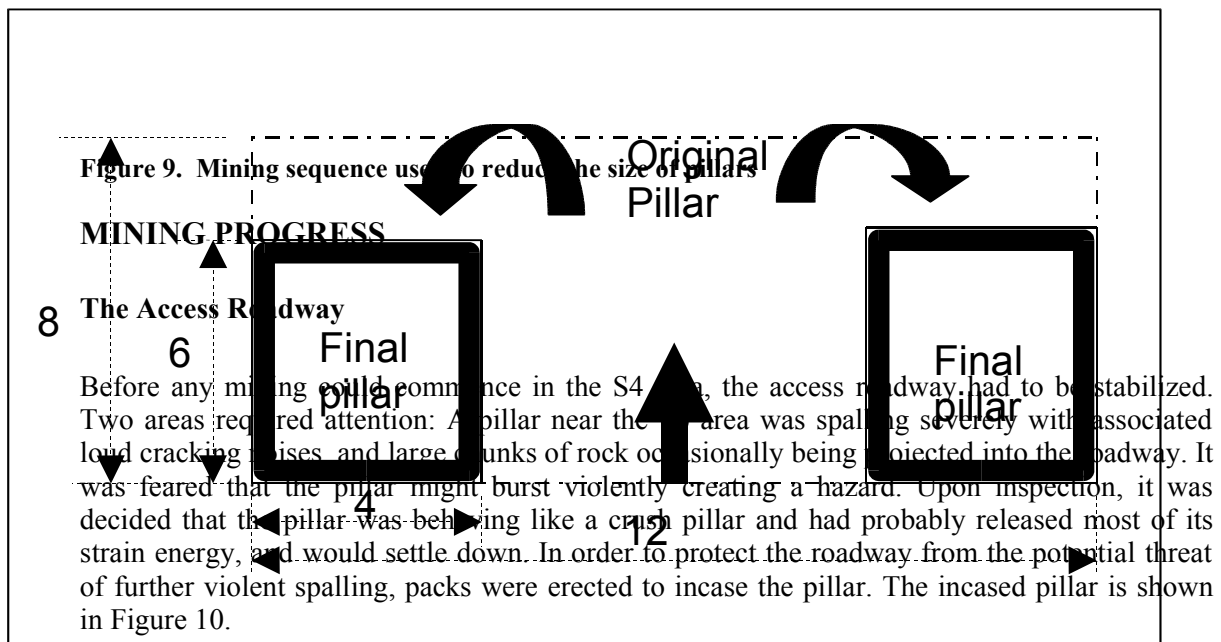


Figure 9. Roadway pillar surrounded with packs
Where the roadway passed through the fault loc 7.5m. Both the hangingwall and sidewalls appear the roadway as shown in Figure 11.

A hangingwall fall of ground in a roadway can common method of re-supporting high roadway a dozer to provide a platform from which re-s becomes impracticable when the hangingwall h in this area would be costly, time consuming and

The most practicable method of supporting Although these packs cannot possibly provide successfully arrested further falls of ground mechanism by which they secure the hanging preventing further unraveling of the hangingwall Figure 12. After the installation of these packs during the pillar mining operations.



Pillar Mining

The pillar mining operations reduced the volume of the pillars by 50 % from one 12m x 8m pillar to two 6m x 4m as shown in Figure 9. The trackless equipment used included a dozer a loader and two tip-trucks which were unable to keep pace with the large volume of broken rock generated by blasting operations.

Blasting and cleaning operations were conducted as rapidly as was possible with blasting operations daily, and a continuous operations schedule applied to cleaning. As mining operations retreated, the mined out areas were barricaded off.

Figure 13 shows a dozer pushing up a rock pile for the loader; here pillar mining has increased the span to 12m. Although the hangingwall remains intact, there is evidence of new cracks appearing along the axis of the roadway.



Figure 12. A dozer operating in a 12m wide roadway

The two 4m x 6m pillars left after the 12m x 8m pillar was cut, were usually found to be in good condition with no evidence of scaling in the initial stages. It was anticipated that the under-stoping would result in footwall punching; however, this did not occur. Figure 14 shows a newly cut 4m x 6m pillar with no evidence of scaling, however, vertical fracturing, which formed in the hangingwall around the perimeter of the pillar shows early evidence of failure.



Figure 13. 3.5m high 4m x 6m pillar

Figure 15 shows a joint opening along the axis of the roadway after pillar mining. By the time this joint was noted, vamping operations in the area were nearly complete and the area was barricaded off.

Figure 14. A joint opening up along the axis of the

Figure 16 shows a large fall of ground that occurred during the mining operation where the roadway span had been increased. This occurred a month after the area had been barricaded.



Figure 15. FOG 5m x 10m 1.5 m high with solid pieces of hangingwall

DISCUSSION

A second phase of mining was safely carried out in the 106 S4 pillar region of the mine. The partial removal of pillars in the area created potentially hazardous conditions including falls of ground, pillar failure, regional failure and middling collapse. Forward planning and continual on-site inspections meant that the mining operation was carried out without injury to personnel or loss of equipment.

Pillar punching, pillar failure and foundation failure did not occur during the six months that mining operations continued in the area despite some pillars exceeding their U.C.S.

Large falls of ground did occur in the abandoned back areas indicating time dependent behavior of the rock.

A pillar next to the access roadway did partially fail, however the pillar was contained and no damage was caused.

CONCLUSIONS

- Increasing the span of the pillar mining roadways from 10m to 12m resulted in large falls of ground between pillars.
- All falls of ground appear to be bounded by steep dipping fractures, which formed next to the pillars, and shallow dipping curved fractures originating from adjacent pillars 1m to 4m in the hangingwall.
- Where falls of ground did occur, generally a time delay of between 1 month and 3 months was noticed between when the pillars were reduced and the fallout occurred.

- The under stoping of the A5 reef appears to have distressed the area, allowing the pillars to yield slightly, thus preventing pillar failure.
- Reducing the size of the pillars rather than completely extracting them appears to have delayed the hangingwall collapse and allowed time for cleaning operations.
- Leaving every third pillar un-mined appears to have helped stabilize the area.
- There was no evidence of middling collapse suggesting that the competent quartzites in the area can support a middling of as low as 10m.

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