Large-scale structural-geotechnical rehabilitation of the Ferreira's Gold Mine, Crown Interchange, Johannesburg

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ABSTRACT: This paper discusses the bespoke structure and geotechnical rehabilitation measures implemented on the Ferreira's Gold Mine, which transformed derelict mining land into valuable real estate in the heart of Johannesburg. The mine - the earliest of the initial large-scale workings in Johannesburg, dating back to the gold rush of the late 1880s - was abandoned in the 1960s, and loosely backfilled with ash from the nearby power station. In the absence of formal rehabilitation, the land was effectively sterilised, precluding any development. Given the value of the land, an ambitious rehabilitation project commenced in 2022 to construct an inclined reinforced concrete bridge deck ~ 200m long, spanning the 15m wide stope and founded 18m below ground. Extensive geotechnical challenges were overcome utilising design-on-the-fly solutions, without the benefit of any exploratory work or time for formal analysis. These included injection grouting of open rock joints while working below a brittle quartzite hanging wall - leaning ~10° into the excavation - installation of a temporary soil nail arch wall at the base of the excavation to facilitate safe grouting operations and plugging of cavities below a 20m ash fill dump, cut at the nominal angle of repose. Notwithstanding the high-risk undertaking, no accidents were encountered in the 18-month project, despite an earth tremor midway through the project.

1 INTRODUCTION

1.1 *Historic development of Ferreira's Gold Mine*

Ferreirasdorp - named after Colonel Ignatius Ferreira, a gold pioneer and founder of Johannesburg - is, reportedly, the oldest part of Johannesburg, sometimes referred to as the "cradle of Johannesburg". This is the site where Ferreira - the leader of the original group of gold diggers - initially settled, in 1886, and commenced the first gold diggings (Meredith 2008).

Ferreira had, evidently, acquired a dozen claims in the vicinity and opened the gold reef in a cutting, from which the ore from both sides of the cutting had a high mineral content.

The city grew around the mining camp in the Ferreirasdorp area, and Johannesburg's Main Street developed from a rough track where the present Albert Street led off towards Ferreira's Camp (Musiker 2000).

1.2 *Mining techniques*

It is evident, from telltale signs on site, that the mining techniques commencing in the late 1800s are likely to have been unsophisticated and executed manually without any mechanical equipment.

In the absence of foreknowledge, it is evident that this initially took the form of surface mining – using so-called *glory hole* extraction, similar to that of the Kimberley Diamond Mine - progressively excavating the ore from several adjacent, indistinct conglomerate reefs exposed between the successive bands of more competent quartzite.

1.3 *Stull stoping*

It is evident that the viability of surface mining of the glory hole became unworkable, relatively soon after commencement- possibly due to the steep dip slope of the reef - following which *underground mining* became the necessary mining mode.

This underground mining appears to have been facilitated by several vertical shafts, and at least one adit tunnel discovered during our rehabilitation works detailed below (Fig. 1).

These conduits provided the necessary access to mine and extract the ore body from below, using a process known as *stull stoping* (depicted graphically in Fig. 2).

In the Ferreira Mine, large timber props, or *stulls*, were clearly socketed into the quartzite footwall, and by bearing on the quartzite hanging wall allowed the removal of the ore-bearing conglomerate reef, leaving a vast void, some 5 m – 15 m wide.

Figure 1. Exposure of an adit (access) tunnel approaching the mine stope from the north beneath Anderson Street

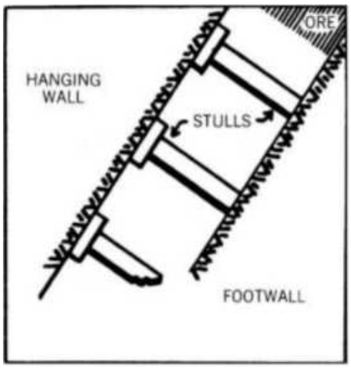

Figure 2. Illustration of the stull stoping process (Peele 1941)

1.4 *Mine closure*

Beyond a certain depth, further extraction of gold bearing reef clearly became uneconomical, following which the various mined stopes were indiscriminately backfilled, in a largely uncontrolled fashion, using a mixture of gravelly soil, comprising the muck and spoils from the mining operations, and a significant volume of ash and clinker, presumably from the old coal-fired power station in the centre of Johannesburg, where the Apartheid Museum now resides.

The net result was the most valuable real estate in Johannesburg - located at the Crown Interchange, parallel with Commissioner and Fox Streets ‒left dormant and sterilised, scarred by the actions of the pre-sustainable mining era, rendering it metastable and of no economic value.

1.5 *Mining asset transformation*

Following the cessation of the mining rights, a management buyout of the Central Rand gold mining assets facilitated the redefining of the original mining company into a property company.

This led to the removal and reprocessing of the many mine dumps which once defined the Johannesburg skyline, transforming this formerly sterilised and unsightly mining land into valuable commercial-industrial real estate, given its proximity to the Johannesburg CBD, typically immediately adjacent to the city's freeway network.

One such rehabilitation project is the abandoned Ferreira's Gold Mine, where the primary vision was to transform this site into an integrated, multi-modal transport hub for Johannesburg, alleviating congestion in the city and facilitating the rapid and efficient movement of commuters.

2 GEOLOGICAL CONTEXT

The formation of the Witwatersrand and the orientation of the Gauteng stratigraphy is essentially attributed to a massive asteroid impact at Vredefort (Fig. 3), which induced the tectonic activity responsible for warping and faulting the once-horizontal sedimentary beds of Witwatersrand Supergroup into a near-vertical orientation (Fig. 4).

This facilitated the exposure and discovery of the gold-bearing conglomerate reef (Turffontein Subgroup) at ground surface at Langlaagte, which was subsequently traced on an east-west arc - tracked by Main Reef Road - from Klerksdorp in the west through to Evander in the east (Fig. 5).

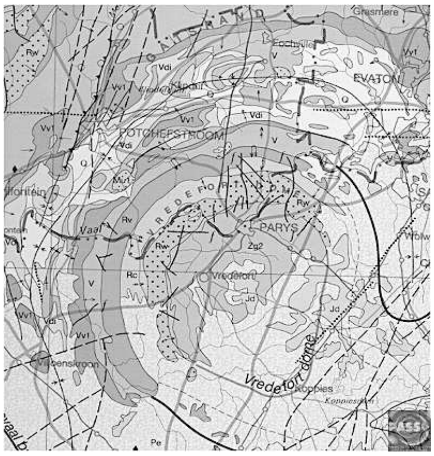

Figure 3. Vredefort impact dome (Earth Impact Database)

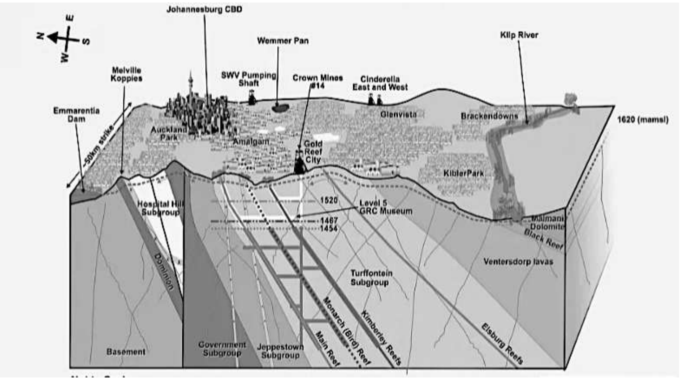

Figure 4. Schematic model of the Central Basin (DWS)

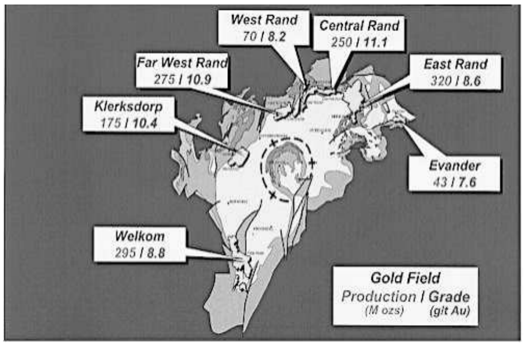

Figure 5. Major Witwatersrand Basin goldfields (Wits Basin)

3 FERREIRA'S MINE REHABILITATION

3.1 *Objectives*

The primary objective of this rehabilitation operation was to transform this sterilised ground – in the heart of Johannesburg at the Crown Interchange – by removing the mining residue and mitigating the underlying stability risk to meet requisite engineering safety standards for future development.

To guide this rehabilitation, a team of structural and geotechnical engineers was assembled to guide the process and provide bespoke, design-during-construction engineering solutions as the needs arose.

3.2 *Supplementary objectives*

One of the supplementary objectives at the outset was the hope that the technical experience gained would be documented to formulate a viable working solution for the rehabilitation of similar, high value, well positioned but derelict mining land throughout the Reef.

3.3 *Conceptual design solution*

In considering the rehabilitation options, it was assumed, by the developer, that the optimal solution to render this site suitable for redevelopment would be the installation of a reinforced concrete deck spanning the mined reef to simply bridge over the void, which would then be backfilled to ground level.

This would necessitate the removal of the stope backfill material to some minimum depth, where suitable quality rock mass could be proven, capable of accommodating the induced bearing pressures.

4 PROBLEMS ARISING

4.1 *Extent of the works*

The early rehabilitation work on the abandoned mine commenced in 2022 and comprised the simple removal of the loose, mixed quality backfill, which comprised a significant proportion of loose, highly compressible ash.

In the absence of any deep investigative work being conducted prior to the rehabilitation commencing, the extent of the mining operations was undefined and costs unquantified, only becoming apparent as the site was progressively cleaned out and opened up (Fig. 6).

Figure 6. Exposure of the mined reef after backfill removal

This led to the works being substantially larger than originally anticipated by the developer, morphing from just the Main conglomerate reef (MR) to include three parallel reefs - namely the Main Reef (MR), Main Reef Leader (MRL) and South Reefs (SR), conceptually similar that shown on Figure 4 – which had effectively collapsed into one another, forming the massive void.

4.2 *Depth of excavation*

In the process of backfill material, an alarmingly deep pit was generated. With no end in sight, and backfill continuing to some indeterminate depth, it became apparent that the base of the stope was not going to be proven in the excavation – deep as it was.

The only real benefit of further deepening was the reduction in the collapse zone between the adjacent reefs, due to an increase in the retained, non-ore-bearing country rock. Closer to surface, this retained rock mass had simply collapsed into the excavation, creating a massive void – particularly at the east end - depicted in Figure 6.

In the absence of this guiding information, and with no real opportunity to establish the ultimate excavation depth, there appeared to be limited value in the continual removal of the backfill, and that a rational cut-off was required.

4.3 *Stability challenges*

Only really through the process of the backfill removal did the sheer magnitude of the mining operations begin to take shape, eventually exposing a nominally 18 m deep stope – at cut-off level - some 200 m long and up to 15 m wide. This slot was formed between a competent quartzite footwall, dipping ~80°

S into the trench, and an extremely brittle, metastable quartzite hanging wall, leaning at a reciprocal 100° into the mined stope as demonstrated on Figure 7.

Figure 7. Joint widening in the hanging wall during excavation

4.4 *Hanging wall instability*

Unlike during the original mining era, where large timber stulls were socketed into the footwall to maintain lateral stability (Fig. 8), these valuable timbers had clearly been removed during the original backfilling operations, fully transferring lateral stability to the backfill material.

On subsequent removal of this supporting backfill, however, the hanging wall was left unsupported, leaning precariously into the excavation, with the near-vertical rock joints opening progressively in the absence of this passive pressure as the backfill was removed (Fig.7).

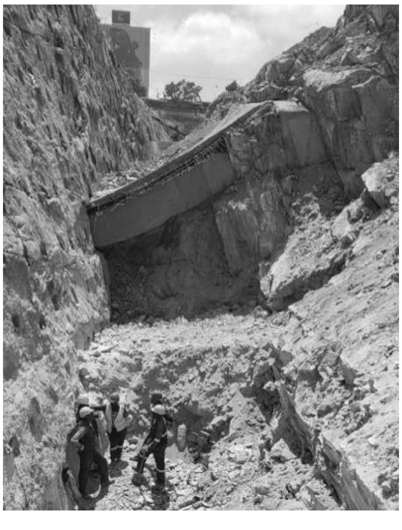

Figure 8. Inclined beam-deck ar-rangement before backfilling

4.5 *Vulnerable rock joints*

As is generally the case, hard rock tends to be more brittle than soft rock, and particularly vulnerable in a case where the bedding planes are parallel with a void.

This was the very case exposed at Ferreirasdorp, where the mined conglomerate reef followed the natural dip of the metamorphosed rock strata, laterally destressing the adjacent quartzite which opened the primary rock joints parallel with the original sedimentary bedding planes (Fig. 7).

4.6 *Slope failures*

The combination of the brittle rock mass, joints opening parallel with the mined stope and the loss of lateral support led to several localised slope failures during the rehabilitation process, many of which were carefully induced to control the timing of failure and limit the potential for accidents.

This was particularly the case in the midspan region (depicted in Fig. 6), which comprised a particularly highly fractured rock mass, likely to have been aggravated, or induced, by a diabase dyke cutting across the bedding planes which appeared to have fractured the proximate quartzite rock mass either side of the intrusion.

5 STRUCTURAL DESIGN

As the excavation work progressed and the physical dimensions and depth of the stope began to be realised, it became apparent that the most cost-effective solution would be to span the void using a structural solution comprising beams and slabs, much like a cast-in-situ reinforced concrete bridge deck.

The main challenge was the shear dimensions involved: some 200 m long and around 15 m wide in the initial section at the east end, comprising highly irregular geometry which was dictated by the stability of the hanging wall (Fig. 6).

5.1 *Self-supported deck*

The structural design made the necessarily conservative assumption that the remnant backfill material below this cut-off depth could simply not be relied upon at all for support, on assumption that this backfill could, at any stage, simply collapse into the voided mined stope below.

As such, all beams would need to be both self-supporting and the deck able to carry its on self-weight in addition to around 18 m of deadload from the compacted soil to be placed on the deck in the closure operation (Fig. 8).

Moreover, in view of the geometry of the stope, the bridge deck needed to be significantly inclined to control vertical movement in the event of a total loss of support of the underlying fill.

5.2 *Excavation cut-off criterion*

It was, moreover, reasoned that once the requisite beams could be installed to the optimised angle to restrain vertical movement - in the event of a total loss of support below - excavation of the fill at the footwall level could be terminated and the sloping backfill merely retained as formwork for the beams, albeit with no reliance placed on any support available.

For each of the beams, the quality of the rock mass needed to be assessed by the geotechnical specialist for load bearing capacity. In the absence of any drilled rock cores, this needed to be established visually, considering the type of rock, the rock mass quality, vertical joint spacing and degree of fracturing.

Given that this was generally better quality, medium hard rock quartzite on the footwall, with joint sets at nominally 300 mm centres, allowable bearing pressures were set at 2 MPa.

In contrast, for the hanging wall, exhibiting lower quality quartzite with open joints, allowable bearing pressures were halved, on condition that the open joints first be sealed through compaction grouting methods to restrain lateral movement.

5.3 *Spreader beams*

For the more critical footwall, the bridge deck was designed to bear on the rock via large spreader beams, which were typically socketed two joint sets into the quartzite to remove the risk of weathered rock and limit lateral movement under load.

For the hanging wall, larger spreader beams were used to increase the contact area, as any chiselling was deemed too dangerous, given the vulnerability of the unsupported slope.

5.4 *Bespoke beams*

Given the erratic nature of the hanging wall, which was periodically deliberately pre-collapsed where excessively unstable, virtually every beam necessitated a bespoke design, determined by the span and the allowable bearing pressures of the hanging and footwalls, which were judged on inspection by the geotechnical specialist, leading to the irregular arrangement of bridge decks illustrated on Figure 9.

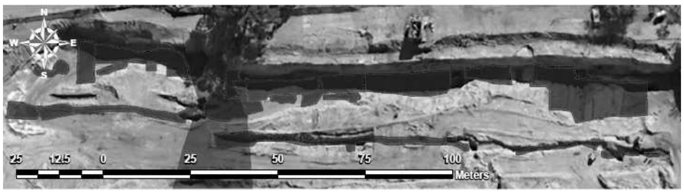

Figure 9. Plan view of completed deck spanning the Main Reef stope

6 GEOTECHNICAL COMPLICATIONS

Despite the relatively routine conceptual design, numerous construction challenges arose during the rehabilitation, necessitating immediate, bespoke, onsite modifications to the design, without the benefit of any further exploratory work or rigorous modelling opportunity. These included:

6.1 *Open rock joints*

On inspection of the early stages of the works, it became clear that lateral movement of the hanging wall was taking place, manifesting as open joints widening vertically towards the surface exposure. In many instances, these joints were measured, by the geotechnical specialist, be to as much as 50 mm.

This posed a severe design challenge for the bridge functionality, where no more than 50 mm of lateral movement could be tolerated, since any greater lateral movement risked rotational instability of the desk, in the event of the underlying fill collapsing.

To mitigate this lateral movement risk, the geotechnical engineer opted to drill into the rock mass behind the spreader beam, to seal any open joints with a cementitious grout of progressively increased viscosity to limit lateral dispersion beyond the zone of value.

Due to the sheer magnitude of the excavation, this was initially undertaken from the south surface above the hanging wall at the eastern extremity, where inclinations to the target zone could be visually assessed.

As the width of the excavation decreased progressively, the more favourable geometry allowed for shorter beams to be installed, albeit at greater depth, precluding the top-down grouting approach and mandating grouting operations be set up in the pit, below the hanging wall, which posed considerable risk.

As the work advanced from east to west, concrete beams and decks were progressively installed in tandem with the grouting operations, providing improved lateral stability of the excavation, allowing the works to continue in a responsible fashion.

6.2 *Unstable rock mass*

In view of its vulnerability to collapse – as evidenced by open rock joints propagating from depth to ground surface - progressive controlled collapsing of the hanging wall was undertaken to mitigate the geometric risk insofar possible. As this had the negative effect of enlarging the bridge deck spans and beam dimensions, it was actioned as a last resort.

Upon entering the midspan zone, the hanging wall was found to be extremely fractured and judged to be leaning too far into the excavation for the grouting operation – which could physically dislodge the rock mass - to be safely undertaken.

To mitigate this risk, a temporary soil nailed arch wall was installed as a protective shield to ensure the safety of the grouting operation, following which this was integrated within the longitudinal lateral support operations (Fig. 10).

Figure 10. Temporary lateral support to facilitate safe construction of the mid-span bridge deck

6.3 *Exposure of Main Reef Leader*

In the process of the rehabilitation west of the soil nail wall, sinister grout takes were encountered, indicating highly fractured - even voided rock - prompting further recessing of the hanging wall. This led to the unearthing of a completely voided secondary stope which, when open up, was found to be the MRL.

With the concrete deck now already installed, a supplementary transfer beam had to be inserted across the void to provide lateral continuity between the MR and MRL. This was then regrouted behind this MRL beam to restrain lateral movement of the bridge deck.

6.4 *Historic adit tunnels*

Near ear the west end of the pit, the footwall excavation unearthed an adit tunnel, cut and perpendicular to the stope beneath Anderson Street (see Fig. 1), necessitating a concrete collar prior to backfilling.

During this process, a further adit was exposed 2 m below the selected footwall buttress, necessitating a lowering of the bridge deck beams, which further destabilising the hanging wall of this zone.

To counteract this risk, a controlled collapse of the hanging wall was triggered by tracked excavator, inducing the need for much longer beams and additional grouting to stabilise this rock face.

6.5 *Diabase intrusion*

A further challenge emerged in the western quartile, where a highly weathered north-west oriented diabase intrusion cut across the east-west bedding planes of the Witwatersrand Supergroup.

In view of the highly weathered nature of the residual diabase exposed at the selected footwall founding depth, which exhibited very limited bearing capacity, no opportunity for the regular beam and deck arrangement was possible.

Since the diabase dyke is non-gold bearing, this feature was logically retained as a *de facto* land bridge by the original miners and assessed to exhibit no risk of undermining.

This allowed a simple jockey-slab arrangement to be used, tying into a fanned bridge beam arrangement following the orientation of the intrusion.

6.6 *Steep ash dump*

The final geotechnical challenge arose at the western extremity immediately adjacent to Anderson Street, which exposed a very steep cut slope into the original loose ash backfill, now standing precariously at the nominal angle of repose. Constrained by the stability of Anderson Street and the municipal water bearing services, extreme caution was undertaken in the installation of the bridge deck in this zone.

7 CONCLUSIONS

In the absence of a geotechnical investigation prior to the commencement of the reef rehabilitation, which may have informed the magnitude of the work, the Client's decision to retain a geotechnical specialist to guide the reef repairs proved to be justified in this instance of structural or geotechnical unpredictability.

This, by necessity, required conservative assessment based on observation and engineering judgment, rather than analytical models of these highly irregular and uncertain conditions, where safety of workmen was considered the overriding consideration.

As such, in the absence of rigorous upfront investigative work to expose the complex conditions which may have somewhat refined the solution implemented - it is unlikely that a more cost-effective approach was available for this project than the professional team guiding the contractor through the rehabilitation works.

8 RECOMMENDATIONS

In circumstances such as this, where there is great uncertainty, insufficient geotechnical predictability and clearly defined and measurable structural solutions, a time-and-cost, design-on-the-go approach is strongly recommended, as this is favourable all parties, particularly when the client has technical competence in-house and there is transparency and trust by all parties.

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REFERENCES

Department of Water Affairs and Sanitation, *Schematic Model of the Central Basin,* https://www.dws.gov.za/iwrp/AMDFSLTS/C%20Basin/default.htm

Earth Impact Database. http://www.passc.net/EarthImpactDatabase/New%20website_05-2018/Index.html

Meredith, M. 2008. *Diamonds, gold, and war: the British, the Boers, and the making of South Africa*. PublicAffairs. pp. 177-179. ISBN 978-1-58648-641-9.

Musiker, N. & Musiker, R. 2000. *A Concise Historical Dictionary of Greater Johannesburg.* Cape Town: Francolin. ISBN 1868590712.

Peele, R. & Church, J.A. 1941. *Mining engineers handbook.* John Wiley & Sons: New York.

Wits Basin Precious Minerals Inc. https://www.nafinance.com/Listed_Co/english/wits_e.htm

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