BACKGROUND
Northam Platinum has embarked on one of the largest expansions undertaken in the platinum sector at its Booysendal operation. The mine plans to increase its current production of 160 000 oz/year to 500 000 oz/year.

The big expansion programme will focus on development of the “South Mine” situated south of the existing Booysendal North Mine. The South Mine Expansion Operation includes the development of:
- Booysendal Central Box-Cut and associated infrastructure
- Booysendal Central Merensky
  - BCM 1 Merensky
  - BCM 2 Merensky
- Operations on the acquired Everest Mine.

ARQ Geotech was appointed in 2015 by DRA Global, the mine’s main Engineering, Procurement, Construction and Maintenance (EPCM) contractor, for the expansion project to provide geotechnical services. This exciting project boasts an array of geotechnical applications for various infrastructure components which are outlined in this article.

LOCATION AND GEOLOGICAL MAKEUP
The Booysendal Mine is situated on the border of the Mpumalanga and Limpopo provinces, with its footprint extending into both provinces. The mine is located about 50 km west of Mashishing (formerly Lydenburg). It is situated on the eastern limb of the Bushveld Igneous Complex (BIC).

An interesting side note
The BIC constitutes the world’s largest ore reserve of Platinum Group Elements (PGEs), chromium and vanadium. Mineralisation in the BIC occurs in three layers: the Merensky Reef and the Upper Group 2 (UG2) of the Critical Zone in the eastern and western limbs, as well as the Platreef of the northern limb. The BIC has a maximum thickness of about 8 km and intruded approximately 2 060 million years ago. Exploitation of the mineralised units of the BIC started circa 1925 mainly on the Merensky Reef and has now expanded to include other reefs, such as the UG2.
THE INFRASTRUCTURE

The Booysendal Expansion Project comprises the construction of several large infrastructure components. Multiple box-cuts in the valley surrounding the Groot Dwars River will serve as portals, bringing ore to surface. From here the ore will be loaded onto an aerial rope-conveyor system (the first of its kind in southern Africa), and transported to processing plants several hundred metres above. Approximately 13 km of access road was required, which triggered the need for significant lateral support and embankment construction operations owing to the steep topology of the area. Several large ancillary structures were also required, including load stations, drive stations, crusher plants and more. The geotechnical attributes of some of the more interesting and unique infrastructure components are presented below.

BOOYSENDAL CENTRAL BOX-CUT

In order to penetrate the mountainside on the west of the Groot Dwars River to gain access to platinum-rich reef, it was necessary to construct a “box-cut” structure. The box-cut serves to expose competent rock at the base of a highwall, in which portals can be constructed without the risk of hanging wall failure.

The Central Decline Box-Cut Development facilitates the entry of seven portals into the mountainside. Invert levels and the inclination of the portals are calibrated to allow maximum “on-reef development” – a good mechanism for subsidising the box-cut and early portal construction.

Some key geotechnical focus areas pertinent to the Central Box-Cut infrastructure are outlined below.

Highwall lateral support

Some significant lateral support was required for the Central Box-Cut Development. The highwall is 650 m long, with a maximum height of 32 m and slope angle of 70°.

After extensive geotechnical investigations, including rotary core drilling, geophysical tests and specialised laboratory testing, a comprehensive geotechnical model was developed, and representative strength and stiffness parameters were assigned to each material. Design work was undertaken utilising finite element analysis methods and checked by hand calculation and limit equilibrium methods, in accordance with good practice. The lateral support measures ultimately consisted of 20 mm diameter soil nails, 9.5 m maximum length, on a 1.5 m grid, declined at 10° below the horizontal.

The construction of the highwall commenced mid-2016 and was completed mid-2017. The support measures implemented have successfully arrested any movement (within tolerable limits) and effectively hold back the mountainside, allowing access to portals (Figure 2).

8.5 ML RESERVOIR

Part of the expansion works at the Central Development included an 8.5 ML reservoir to be constructed on the terrace platform. The area that the reservoir was to be founded on had a complex geotechnical history, having been the historic location of a large erosion gulley which was subsequently backfilled with rockfill.

Due to the many uncertainties associated with the soil and rock profile, rotary core drilling was completed on the footprint of the proposed reservoir and a 3D geotechnical model was compiled for 3D finite element analysis (Figure 3).
From the analysis, the extent of differential settlement and applied vertical stress on the foundation was determined. Coupled-consolidation methods allowed geotechnical engineers to answer settlement questions not only in terms of “how much”, but also in terms of “how long” – an important consideration when investigating what proportion of settlement will occur during and after construction.

It was ultimately determined that, to bring the total and differential settlements into allowable limits, the reservoir should be founded directly on a 4 m thick rockfill mattress which overlies the in situ substrata. The structure is currently under construction.

**MECHANICALLY STABILISED EARTH WALL**

The mechanically stabilised earth wall (MSEW) situated on the northern portion of the Central Development, with a maximum height of 11 m, was designed by Reinforced Earth (Pty) Ltd in respect of internal stability, and by ARQ Geotech for global stability and founding (Figure 4).

During geotechnical investigation ARQ encountered a thick clay layer at the foot of the MSEW. Global stability analysis indicated that the presence of this clay layer facilitated the formation of a deep-seated slip, which threatened to propagate below the otherwise suitably reinforced soil mass.

Analysis revealed that the most cost-effective means to remedy the situation was to remove the low-strength material and replace it with a G6-quality fill material.

This was a lesson learned in the value of a thorough geotechnical investigation, as well as in careful consideration of the global stability, in addition to the local/internal stability of such structures.

**CHANGE HOUSE AND OFFICE BUILDINGS**

A state-of-the-art change house, boasting a solar-driven heating system that can produce hot water for over 2 000 people, and an office building with a control centre that will control underground mine operations remotely, form part of the infrastructure at Central Development.

The ground conditions below the footprint of the buildings consist of a thick (~3 m) rockfill layer with large rock fragments in a loose granular matrix. This layer is susceptible to movement once loaded and, in order to mitigate any differential settlement, in situ treatment via dynamic compaction was determined as the optimal mechanism of improvement.

The depth of influence, reduced vibration and the close pad spacing afforded by the rapid impact compaction (RIC) method is a good fit and was therefore utilised. Compaction imprints on a grid spacing of 3.2 m “with one in the middle” were specified, and a maximum of 35 blows per pad with the 9 ton hammer proved sufficient to improve uniformity and minimise settlement potential (Figure 5).

Continuous surface wave (CSW) testing was used as a quality control mechanism to quantify the post-RIC stiffness profile across the site and to confirm uniformity.

**NORTH AND SOUTH ROPE CONVEYORS**

**South RopeCon**

The Booysendal South Rope Conveyor (RopeCon) system is unique and the first of its kind in southern Africa. It comprises a series of towers connected by a conveyor belt and ropes. The system will convey ore from the Central Development to Everest Mine, some 4 km distant. This is a more efficient mechanism for transporting ore up and out of the steep valley than other conventional modes, such as trucking by road.

The tallest tower is an impressive 60 m in height, and the longest span between towers is an incredible 878 m.
ARQ was privileged to be responsible for the geotechnical aspect of the foundation design for this impressive structure. The large foundation dimensions associated with these towers necessitated both a near and a deep subsurface investigation to mitigate the risk of differential settlements and angular distortion.

Most foundations were placed directly on bedrock, but in areas where bedrock was deep, a carefully designed soil mattress was employed to provide the required support.

Construction of the South RopeCon is complete and operation has commenced (Figure 6).

North RopeCon
The North RopeCon system, a second proposed RopeCon leg, will convey raw ore from the Central Mine Development to the Booysendal North Complex. This system comprises a loading station, seven intermediate towers, and a drive station.

Similarly to the South RopeCon, most of the tower structures were founded directly on bedrock with a few exceptions, Tower 7 being one. Tower 7 required major geotechnical attention due to the complexity of the underlying geo-materials and its unfavourable positioning (Figure 7).

Tower 7 is situated close to a batter slope of the Central Development terrace fill – this implied that slope stability considerations would need to be taken into account as the base lies within the mass of soil that would be mobilised in a slope failure. Furthermore, the fill material on which the base will be placed is loose and voided in places (containing large boulders). To make matters worse, this concerning fill is underlain by an in situ clay strata of low stiffness and strength. Clearly, a well-thought-out geotechnical solution would be required.

Initially a raked self-drilling anchor (SDA) micro-pile solution was conceptualised. Considering the magnitude of the loads and the large hard rock boulders in the rockfill layer, the micro-piling solution would have required a total of 64 micro-piles, with half of the micro-piles raked at an angle of 45° to aid slope stability. This proposed solution proved to be extremely costly.

Ultimately, a hybrid solution comprising permeation and compaction grouting, along with limited micro-piling, was developed. Grouting will be used to treat the low-density granular fill and consolidate it into a mass that is much more resilient to settlement and slope failure. A reduced number of micro-piles will then be installed (using the more cost-effective “open hole” installation method through the grouted body), providing improved vertical load bearing within the clay layer.

Two-stage grouting will be conducted using Tube-A-Manchette (TAMS) with variable water:cement ratios. The initial grouting will consist of a more flowable grout to penetrate the fill material in order to fill any cavities. The second stage of grouting will consist of a much lower water:cement ratio / thicker grout mixture, and will densify the material through displacement.

The compaction grouting solution is currently being implemented and is scheduled to be completed by the end of April 2019.

AN EXPANSION WITH LONG-TERM BENEFITS
The Booysendal expansion has currently passed its halfway mark and is planned to be completed by 2022/2023. This large-scale investment by Northam Platinum shows a very positive attitude towards South Africa’s future and its PGM sector.

It has been a privilege for ARQ Geotech to be involved in this momentous project involving such a wide variety of geotechnical applications. It has also been refreshing to work with a client/project management team who appreciates the need for comprehensive geotechnical studies and designs.

![Figure 7 Drawing of Tower 7’s proposed foundation solution](image-url)