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# Study on mechanical properties of surrounding rock and shaft safety pillar in exploitation of extremely thin reef

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**Abstract.** In view of the engineering geological conditions of the extremely thin reef of platinum gold mine in South Africa, we researched the distribution of in-situ stress, seismicity and fault, the relationship between UCS and loading and so on. On this basis, we delineated the shaft safety pillar by using 3D mining software, and analyzed the influence of safety pillar on shaft stability by using FLAC3D numerical simulation method. The results show that it is necessary to set up accurate safety pillars to ensure the stability of shaft even though the height of goaf is very small in the mining of extremely thin reef. Research shows that the safety pillar calculated by numerical simulation method is more accurate, which avoids the resources loss or poor security caused by the traditional method. It is easier to achieve the expression of two-dimensional plane, and is more convenient to calculate the volume amount of safety pillar. The research provides theoretical guidance for the mining design, and has important practical significance.

## 1. Introduction

Bushveld Complex contains a large amount of platinum gold resources that is widely distributed in South Africa, and is mainly in steep and extremely thin reef[1-2]. The exploitation of this kind of resource is usually affected by its small thickness and the large inclination angle. For the special engineering geological conditions such as rock property, geological structure, reef shape, exploration depth, the traditional method for determining shaft safety pillar by moving angle can not meet the actual situation[3-4].

Shaft engineering is very important for most underground mines, many important tasks, such as mining, personnel transportation, ventilation, drainage, power supply, need to be completed through the shaft. When the reef is very close to the shaft, it is necessary to precisely set up a safety pillar to ensure that the shaft will not be damaged by mining activities. If the safety pillar is too large, it will cause serious resources loss, if the pillar thickness is too small, it is not conducive to the safe operation of shaft[5]. Therefore, it is an important research topic to ensure the shaft safety.

The traditional method for determining shaft safety pillar is usually drawn by means of three viewpoints plan that requires multiple fixed-point and section, and the procedure is very cumbersome and the result is not very accurate[6-7]. In order to solve these problems in this paper, we delineated the shaft safety pillar by using three-dimensional mining software based on the research conclusion of



engineering geology and surrounding rock properties, and used FLAC3D numerical simulation method to analyze the influence of safety pillar on shaft stability..

## 2. Background introduction

Lesego platinum project is located in north east of Bushveld Complex (BIC) that is the largest and oldest known layered igneous complex in the world. The BIC is dated at between 2.06 Ga to 2.058 Ga. It is situated in the tensional tectonic environment and the structure intersection zone of the north edge of Archean Kaapvaal Craton. The tectonic framework of the Kaapvaal Craton control the emplacement of this massive Proterozoic intrusive body. The BIC was emplaced and exhibits a transgressive relationship to the Transvaal Supergroup (TS), a large sedimentary basin of late Archaean-Proterozoic age.

In Lesego Platinum mine area, both the MR and UG2 chromitite display geological continuity and same attitude. According to reef interpretation, the reef morphology is layered, and it looks like an irregular plane in horizontal plan. The strike length of each reef is more than 8 km in north-south direction, and the width is between 3 to 4.5 km in east-west direction. The maximal depth of MR is 2,050 m below surface and 2,350 m for UG2 chromitite, with the dip angle of 87 degree near the anticline axis to 7 degree away from axis (See Figure1). The thickness of MR reef is 1.0m~1.4m, with an average thickness of 1.08m. The thickness of UG2 reef is 1.0m~1.4m, with an average thickness of 1.33m.

The primary access we designed to the reef was a twin vertical shaft system that included a main shaft and a vent shaft, the main shaft was sunk to a depth of approximately 1,229 mbs, the vent shaft was a raised hole through sectional construction, ramp and main shaft are simultaneously constructed from the ground surface (See Figure 2).

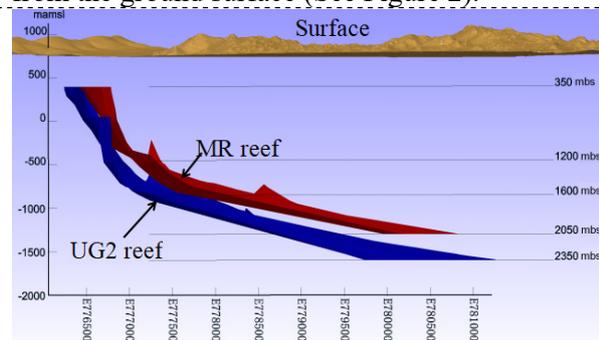


Figure 1. Cross section view of the MR and UG2 reef.

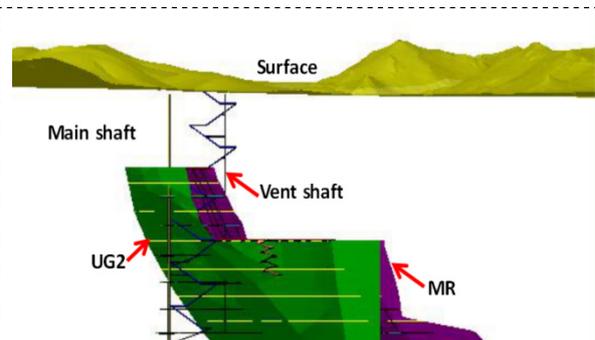


Figure 2. Development system and reef cross strike direction.

It is not recommended to arrange main development tunnel within movement range of the rock, and in order to protect the shaft and other building structures, shaft pillar shall be required. Safety pillar is to keep part of tentatively unexplored reef around the shaft.

## 3. Mechanical properties of surrounding rock

### 3.1. Engineering geology in mining area

The underground mining will commence at approximately 700 mbs (metres below surface) and terminate at 2300 mbs. This environment is classified as shallow to intermediate.

The horizontal to vertical stress ratio (k-ratio) will typically be 1.0 (Figure 3) for the shallow resource and 0.5 for the intermediate depth resource. Confirmation of the k-ratio must be planned and implemented during the capital development phase of the project. This confirmation should take the form of in situ stress measurements using the overcoring strain rosette technique or acoustic emission methods based on the Kaiser effect of core[8].

Although there is some evidence of small scale faulting, typical of all Bushveld Complex mines, the continuity of the mapped horizons suggests an absence of large scale faults in the area. For the

purpose of this study, the entire mining tenure can be treated as a single structural domain and only subdivided on the basis of the attitude and dip of the reef[9]. According to the number of recorded damaging events (see the Figure 4), the mining environment can be divided into two seismic regimes as follows:

A very shallow to shallow resource with geomechanical response of the rock mass dominated by instability on geological structures rather than the effects of stress or mining induced seismicity located between 700 to 950 mbs.

A intermediate depth resource located above 1000 mbs where the influence of stress and onset of seismicity will dominate rock mass response to mining.

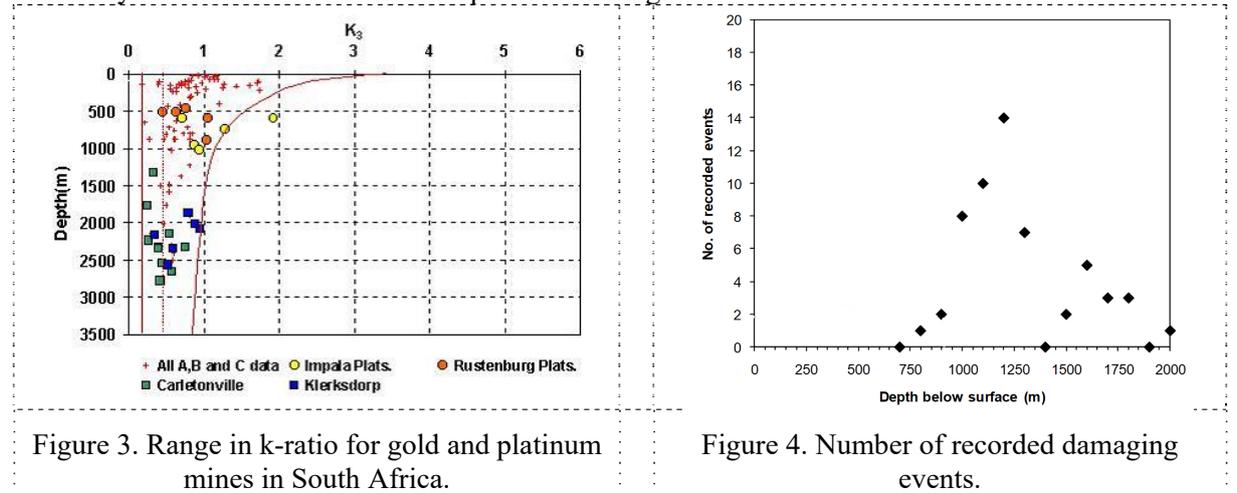


Figure 3. Range in k-ratio for gold and platinum mines in South Africa.

Figure 4. Number of recorded damaging events.

### 3.2. Mechanical properties of surrounding rock

The correlation between UCS (Uniaxial Compressive Strengths) and Is (Load strengths) for all rock types indicated that the relationship:  $UCS=14 \times Is$  will provide a reasonable correlation between field and laboratory test results (Fig.5). Almost all correlation equations show a range of gradients between 10-15 rather than the value of 24 commonly reported in textbooks[10].

The variation of RMR values with depth below surface for all boreholes logged is shown in Figure6. The depth variation indicates that 85% of the ratings are either ‘good’ or ‘very good’ and only 15% ‘fair’. None of the ratings indicate ‘poor’ rock mass conditions.

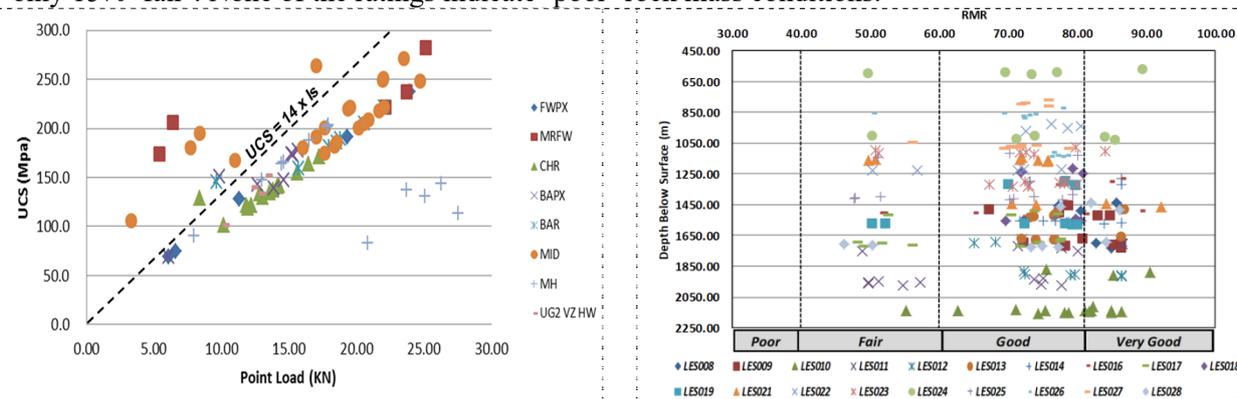


Figure 5. Correlation between load strengths and UCS test results for all rock types.

Figure 6. Rock mass ratings related to depth below surface.

## 4. Numerical simulation of shaft pillar

### 4.1. Build a numerical simulation model

Numerical simulation software FLAC3D is used to model and calculate the safety pillar of shaft. To choose the direction of vertical reef as the X direction, the vertical direction as the Z direction. The model size is 2,000m (length)  $\times$  1,250~1,400m (height), and has a total of 3,696 units and 5,790 nodes. The outline of numerical model is shown in Figure 7. The mesh generation of numerical model is shown in Figure 8.

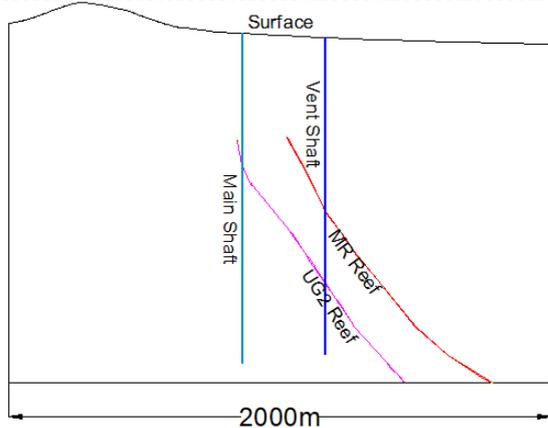


Figure 7. The outline of numerical model.

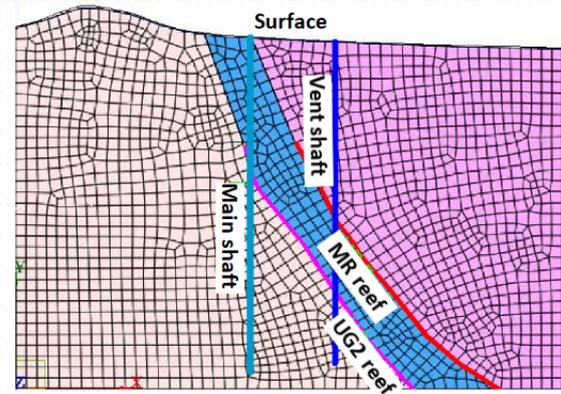


Figure 8. The mesh generation of numerical model.

#### 4.2. Numerical simulation results

The rock mechanics parameters and stress condition in front of this section are input into the model, and Hoek-Brown strength is used to reduce the rock mechanical parameters based on the general Mohr- Coulumb criterion in FLAC3D.

Figure 9 shows that the displacement distribution after UG2 reef being mined with the shaft pillar. It can be seen that the vertical displacement of the main shaft is very small and evenly distributed in the case of the reserved safety pillar, and the horizontal displacement distribution of the main shaft is very small, which will ensure that the main shaft will not be affected.

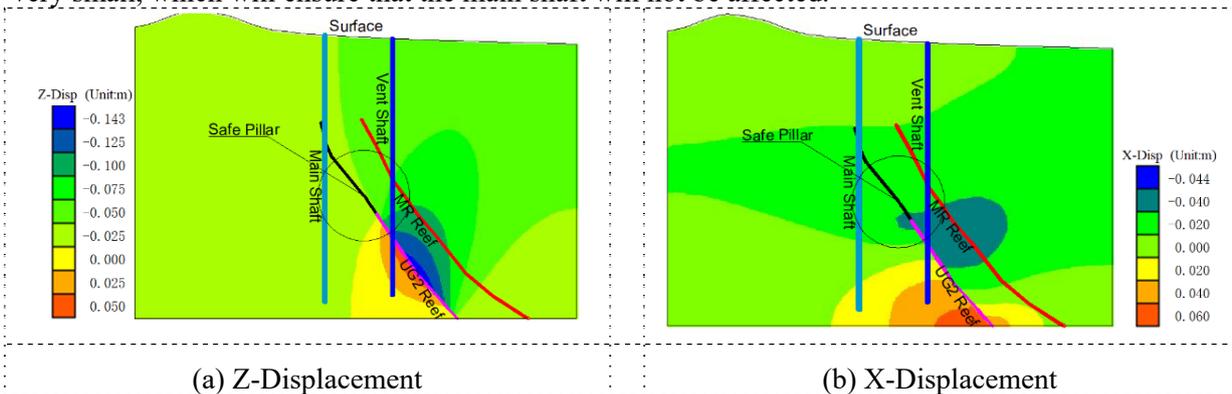


Figure 9. Displacement distribution after UG2 reef being mined with the shaft pillar

Figure.10 shows that the displacement distribution after UG2 reef being mined without the shaft pillar. It can be seen that the vertical displacement of the upper and lower parts of the main shaft is different without leaving safety pillars, and the horizontal displacement of the main shaft varies greatly, these will cause the main shaft to crack locally and affect its normal operation.

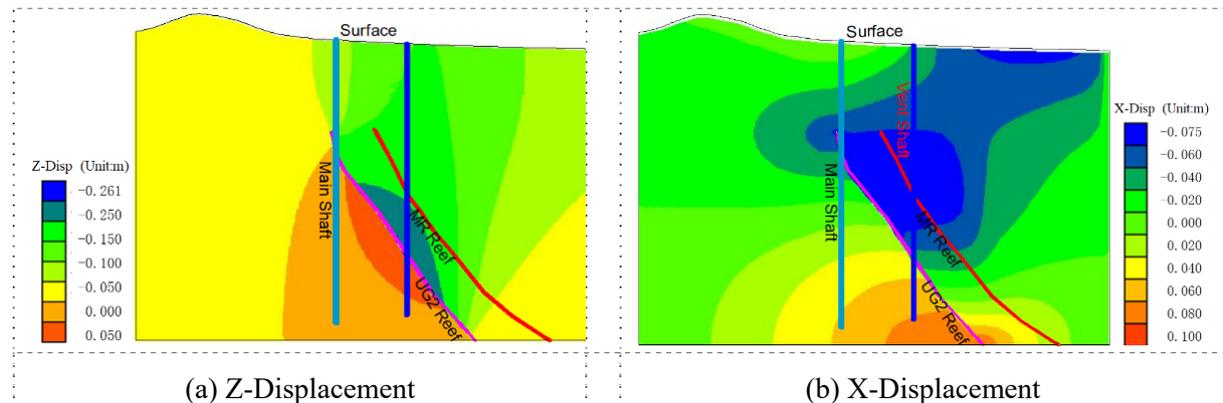


Figure 10. Distribution after UG2 reef being mined without the shaft pillar

Through numerical simulation analysis, it is suggested that the safe pillars should be reserved for the main shaft so as to avoid the influence of mining activities on the main shaft. The 3D sketch layout of final shaft pillar is shown in Figure 11. For the vent shaft, because there is not lifting equipment in it, the displacement of the mining activities will not affect its normal operation.

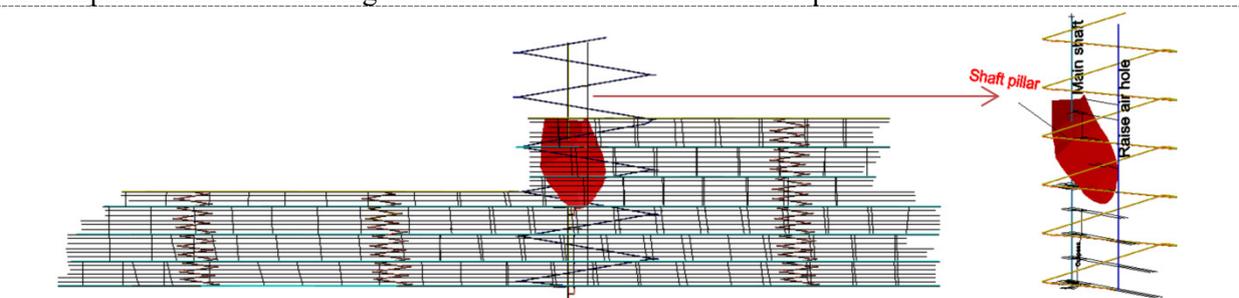


Figure 11. 3D sketch layout of shaft pillar.

## 5. Conclusions

(1) In this paper, the engineering geological conditions and mechanical properties of surrounding rock of a platinum-gold deposit in South Africa were studied, including the distribution of in-situ stress, seismic, fault and the relationship between UCS and  $I_s$ . The research shows that the surrounding rocks located less than 750 to 900 mbs with geomechanical response of the rock mass was dominated by instability on geological structures, while the surrounding rocks located greater than 1000 mbs where the influence of stress and onset of seismicity will dominate rock mass response to mining. In addition, the depth variation indicates that 85% of the ratings are either 'good' or 'very good' and only 15% 'fair'.

(2) Based on the study of engineering geology and surrounding rock conditions of extremely thin reef in platinum gold deposit, the shaft safety pillar was delineated by using three-dimensional mining software and FLAC3D software. Through numerical simulation analysis, it is suggested that the accurate safety pillars should be reserved for the main shaft so as to avoid the influence of mining activities on the main shaft. It can not only easily achieve the expression effect of two-dimensional plan, but also conveniently calculate the volume amount of safety pillar.

## Acknowledgments

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