Application of Surpac and Whittle Software in Open Pit Optimisation and Design*

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Abstract

This paper studies the Surpac and Whittle software and their application in designing an optimised pit. Exploration data from Mpeasem Gold Mining Project (MGMP) is used as the primary input for the work. The work entails: block modelling of MGMP deposit; pit optimisation; analysis of the Pit NPV's sensitivity to changes in gold price and mining cost; and detailed pit design. The deposit has undergone intense weathering, forming an oxidised gold deposit up to about 50 m in depth. Sections through the deposit were used to create a solid model of the orebody, which was divided into blocks to form a block model comprising unit blocks measuring 20 m x 20 m x 10 m. The block model grade was estimated using the Inverse Distance Weighting (IDW) method, giving an average grade of 1.533 g/t with 22.79 Mt of ore. During the optimisation, a total of 82 optimal pit outlines were generated using the 3D Lerchs-Grossmann algorithm. Pit 36 was chosen having the highest the Net Present Value (NPV) @ 10% of $338.60 million. The optimal pit had 21.19 Mt of ore at an average grade of 1.557 g/t. The NPV was very sensitive to gold price changes but marginally sensitive to mining cost changes. From the optimal pit, a detailed pit designed with circular ramp was selected over one with all-cut ramp since it had a higher expected revenue and lower stripping ratio. It is concluded that Surpac and Whittle software combine as a powerful tool for designing an optimal pit.

Keywords: Modelling, Optimisation, Design, Surpac, Whittle.

1 Introduction

The objective of operating an open pit mine is to achieve maximum ore recovery at the lowest possible cost and thus derive maximum profit (Ramazan and Dimitrakopoulos, 2012). This can only be achieved if careful planning and design of the pit is done, which is governed by the need for high productivities, the ability to mine lower grade ores and the need to meet more stringent environmental constraints. Owing to high capital requirements and ever-changing economic factors, every company should design an optimised pit that will have high value and is very stable in the face of economic changes; ensure maximum extraction, low stripping ratio and at the same time satisfy all the slope constraints (Aseidu-Asante, 2012). Lack of optimisation and poor design can have adverse effects such as: inability to achieve maximum ore recovery and maximum profit or premature closure of the mine as a result of any unforeseeable reduction in metal price in the market. The work involved in open pit optimisation and design is so laborious that it is almost impossible to do it manually. Fortunately, there are computer software such as Datamine, Minemap, Mineshed, Surpac and Whittle that assist mining engineers to do the work. In this study, Surpac and Whittle software are used simply because of their availability; they are also widely accepted in the mining industry. Both software are menu driven and combine as a powerful tool for open pit optimisation and design.

2 Materials and Methods Used

Surpac and Whittle software are used for pit optimisation and design in this work. The exploration data from Mpeasem Gold Mining Project (MGMP) is used as the primary data input to demonstrate how Surpac and Whittle software are applied in the pit optimisation and design.

2.1 The Mpeasem Gold Concession

The Mpeasem gold concession measures approximately 52.63 km^2. It lies within the Upper Denkyira District in the Central Region and the Amansie West District in the Ashanti Region of Ghana. The concession falls within the Precambrian Birimian rock formation of Ghana. The gold mineralisation is found in the quartz veins in the Lower Birimian rocks. The upper horizon of the veins (40 - 60 m depth) has undergone intense weathering and has resulted in the formation of oxidised gold deposit.

Beneath the upper horizon is a zone of mixed oxides and sulphides. According to Mireku-Gymah (1997), the gold mineralisation in the quartz veins may be related to metamorphic and hydrothermal events. The oxidised orebody has an average width of about 25 m and a depth of 50 m dipping at 80^o.

2.2 Pit Optimisation and Design

This entailed three sequential steps. The first step was block modelling of the orebody using Surpac

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software. In the second step, the block model was then exported to Whittle software for pit optimisation. Finally, the optimal pit from Whittle was exported to Surpac software for the detailed pit design.

2.2.1 Modelling of the Deposit Using Surpac

The exploration data obtained from MGMP was used as the primary input for block modelling. The data was organised into text files using Microsoft Excel in a format that was manageable within the database facility of Surpac software to facilitate the modelling process. The text files were classified under the titles collar, survey, assay and geology. Tables 1, 2, 3 and 4 show part of each file respectively.

Table 1 Part of the Collar Text File (Collar.txt)

Hole ID	Northings (m)	Eastings (m)	Elevation (m)	Maximum Depth (m)
BH1	175821.0	158910.1	168	14.42
BH2	175675.4	158855.2	168	20.57
BH3	175440.8	158535.3	168	32.62
BH4	175740.4	158862.2	168	29.7

Table 2 Part of the Survey Text File (Survey.txt)

Hole ID	Depth (m)	Dip (^{o})	Azimuth
BH1	0.00	-70	135
BH1	4.86	-70	135
BH1	5.00	-70	135
BH1	10.00	-70	135

Table 3 Part of the Assay Text File (Assay.txt)

Hole ID	Sample ID	Depth from (m)	Depth to (m)	Assay values (g/t)
BH2	221	0	5.57	0.41
BH2	222	5.57	8.56	0.48
BH2	223	8.56	11.57	0.93
BH2	224	11.57	14.57	0.92

Table 4 Part of the Geology Text File (Geology.txt)

Hole ID	Depth from (m)	Depth to (m)	Rock type
BH3	0.00	5.20	RS
BH3	5.20	10.11	RP
BH3	10.11	10.41	QTZ
BH3	10.41	10.66	GP

2.2.1.1 Creating the Database in Surpac

A geological database was created and the text files were loaded into it. Any data input that was not matching with the definitions made in the database was automatically rejected, thus making this stage a data validation process. After loading the database, plans and sections were extracted from the database for plotting and display using the display module of Surpac.

The production of drillhole layout (plan) helps engineers and geologists to familiarise with the plan and drillholes pattern and make conclusions as to which plane to take the sections through. Sections were taken along the eastings from 158350E to 159660E at different intervals. These sections were then used in the delineation and digitisation of the ore zones constrained at 0.5 g/t cut-off grade. Surpac uses a string concept to define objects. A string is an organised sequence of X, Y and Z coordinates with an identifier and can be joined together by lines (Anon., 2000). There are three kinds of strings:

(i) open string;

(ii) closed string; and

(iii) spot height string.

An open string is one in which the first and last co-ordinates are different, and can be employed to depict features like the crest and toe of benches. A closed string is one in which the co-ordinates at the beginning and ending points are the same while a spot height string is a set of random points connected together by a string number, but not outlining any specific feature. In delineation of the ore zones, closed strings were digitised in the clockwise direction. In Surpac, an area digitised in the clockwise direction is characterised as a solid block while an area digitised in the anticlockwise direction is computed as a void. The ore zones in all sections were digitised, forming a series of ore zone strings of the orebody. The strings were then triangulated to form a solid model (Fig. 1), which was subsequently validated.

2.2.1.2 Block Modelling

The following steps were taken during the creation of the block model, using the block model module of Surpac:

(i) Create an empty block model;

(ii) Add attributes;

(iii) Add constraints; and

(iv) Fill the model with attribute records.

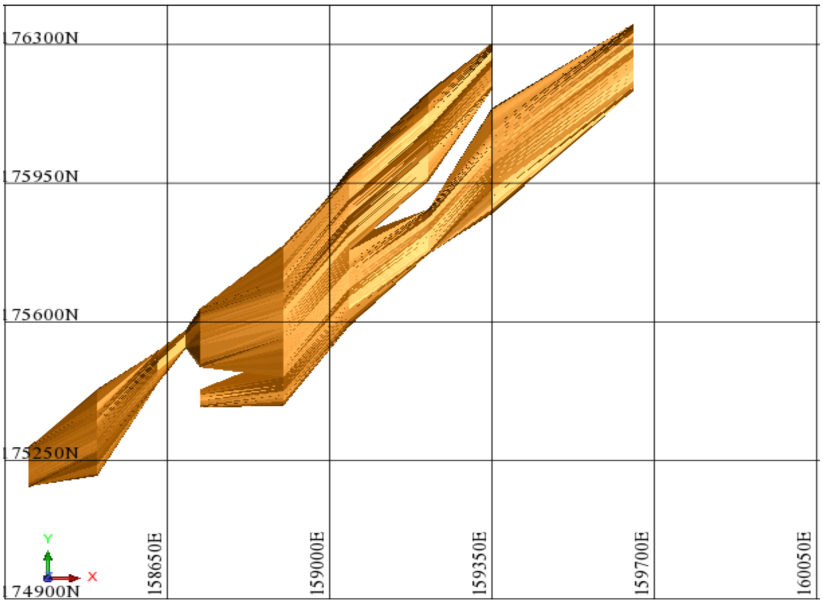

Fig. 1 Solid Model of Orebody

Creating a Block Model

Block model creation involved the definition of the model name, its boundaries and block size. On the basis of the mining bench width and the mining bench height, a user block size of 20 m x 20 m x 10 m was used.

Attributes

Attributes were added into the empty blocks so as to contain the information of each block in the block model. The attributes were the properties that were to be used in Whittle software during the optimisation process. They included the grade, specific gravity, air, waste, rock type, Mining Cost Adjustment Factors (MCAF), and the Processing Cost Adjustment Factors (PCAF).

Constraints

Constraints were used to control the selection of blocks from which information was retrieved. They also aided in viewing the model in graphics. A constraint is a logical combination of one or more spatial objects employing logical operators, and which are intersected with the model to permit operations on chosen blocks (Anon, 2000).

Some of the constraints types used were: Digital Terrain Model (DTM) of the topography, which was used as a boundary between the air and the rock; block attributes such as the grade, which was used to define the waste and the ore using a set cut-off. The constraints were also saved for re-use and to be used as components of other constraints for the calculation of the pit volume.

Model Filling

Some model attribute values were filled directly while others, like grade, had to be assigned by interpolation. Table 2 shows the attributes that were assigned directly.

Table 2 Attributes Assigned

Parameter	Value
Specific gravity for ore	2.73
Specific gravity for air	0.00
Mining Cost Adjustment Factor (MCAF)	1.00
Processing Cost Adjustment Factor (PCAF)	1.00

Block Grade Estimation

In order to do the grade estimation for the block model, a variogram analysis was first done so as to get the maximum search distance and the anisotropy factors that were to be used for the estimation of the grades. The results of the analysis are shown in Table 3.

Table 3 Variogram Analysis Results

Parameter	Value
Maximum search distance (m)	71.25
Major / Semi-major ratio	1.09
Major / Major ratio	1.15

The variogram analysis results were then used in the block grade estimation. Inverse distance method in Equation (1) was used in the calculation of the grades of the various blocks. Inverse distance weighting is a method which applies a weighting factor that is based on an exponential distance function to each sample with a set parameter about the central point of an ore block (Anon., 2004). The weighting factor is the inverse of the distance between each sample and the block centre raised to the power 'n', where n is a positive integer.

$$Z_B^* = \frac{\sum Z_i \frac{1}{d_i^n}}{\sum \frac{1}{d_i^n}} \qquad (1)$$

where:

Z_B^* is the estimated grade;

Z_i is the value of sample at location i;

d_i is the separation distance from point i to the point of reference;

n is the power index (n=2 in this paper).

After the grade estimation, and filling the block model with the attribute values, a validation of the block model was done, ready to be exported to Whittle software for optimisation. Fig. 2 shows the block model that was exported.

2.2.2 Optimisation Using Whittle Software

The steps outlined in Fig. 3 were followed during the optimisation process.

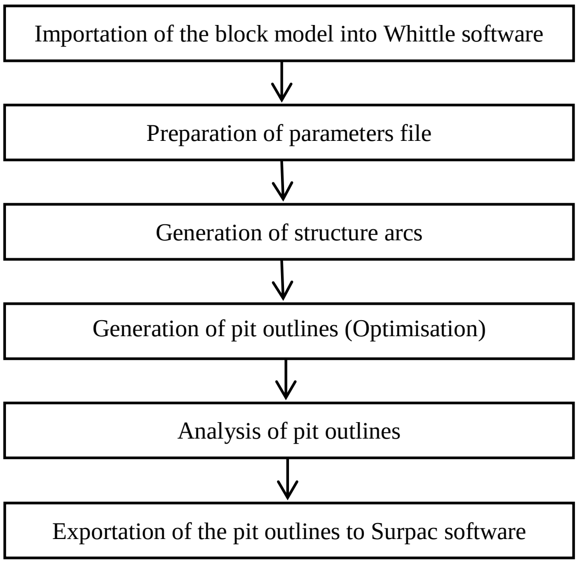

Fig. 3 Steps in Optimisation Process

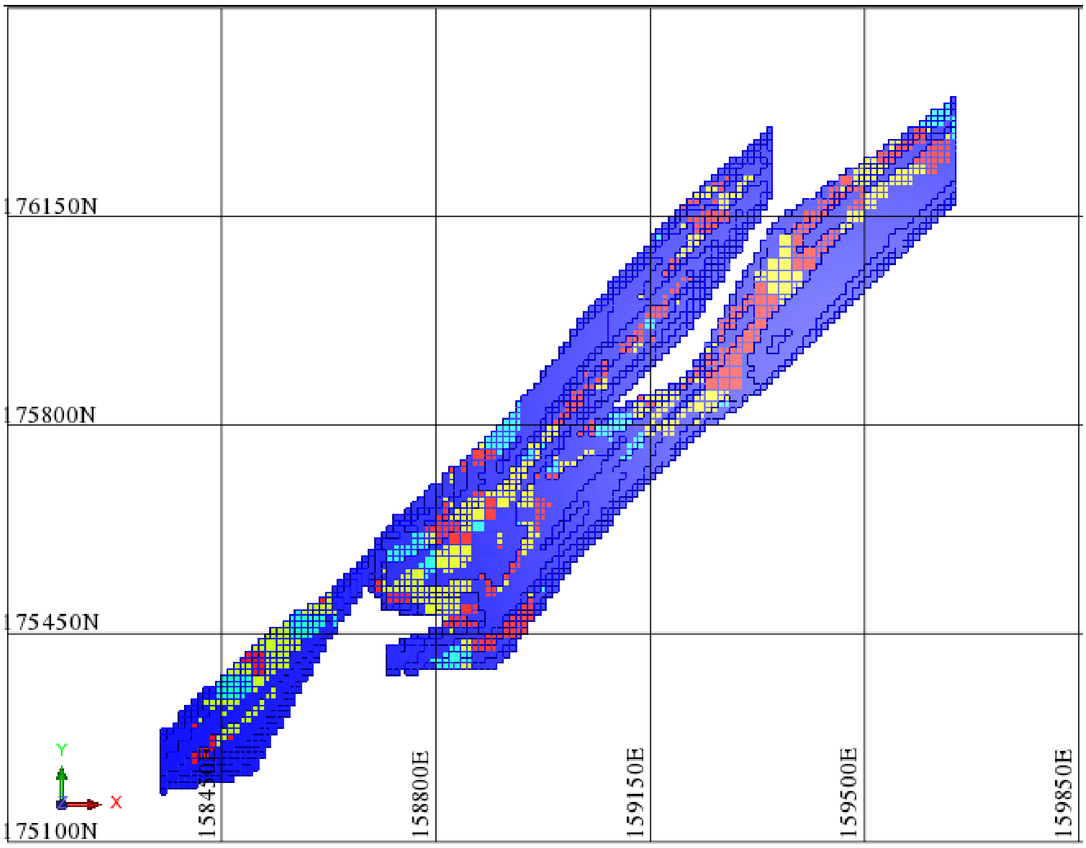

Fig. 2 Block Model

2.2.2.1 Importation of the Block Model

The block model and the parameters file were imported into Whittle from Surpac ready for the optimisation and analysis.

2.2.2.2 Preparation of Parameters File

All the technical and economic parameters that were needed for the optimisation were all set in the parameters file. They included: the cost figures, overall pit slope angle, mining recovery, mining dilution and the revenue factor range.

The cost figures used in this study were taken from the MGMP pre-feasibility study report and some from typical surface mining operations in Ghana. For easier application in Whittle software, all the costs were expressed in mining cost per tonne or processing cost per tonne, and the gold price was expressed as dollars per gramme. Table 4 summarises the figures that were used during the optimisation.

2.2.2.3 Structure Arcs Generation

The Whittle pit optimiser uses the 3-D Lerchs-Grossmann algorithm. According to Whittle (1993), Lerchs-Grossmann method works with only two types of information. These are the block values and 'arcs'. An arc shows the relationship between blocks, that is, which block should be mined to expose another block of value. In this work, 4 163 260 arcs were generated and a structure arc file was created to be used in the generation of pit outlines.

Table 4 Figures Used During the Optimisation

Cost per tonne of mining	\$ 5.913
Cost per tonne of processing	\$ 10.622
Price of gold	\$32.15/g (\$915/oz)
Selling cost	\$0.88/g (\$25/oz)
Capital cost	\$55 362 000
Discount rate	10%
Variable bench cost	\$0.012/bench
Mining recovery	95 %
Mining dilution	5 %
Overall pit slope angle	45^o
Revenue factor range	0.3 to 2.0 at 0.02 steps

2.2.2.4 Generation of Pit Outlines

The 3-D Lerchs-Grossmann algorithm achieves its aim by manipulating the block values and the structure arcs to find the optimal shape for an open pit in three dimensions (Hustrulid *et al*., 2013). It uses an orebody block model, and progressively produces a list of related blocks that should, or should not, be mined. In this work, a total of 82 optimal pit outlines were generated and a results file was then created containing the different pit outlines and details of the blocks within those outlines, ready for analysis.

2.2.2.5 Analysis of the Optimisation Results

The graph of Net Present Value (NPV) at a Minimum Rate of Return (MRR) of 10% against the pits was plotted for both the best and the worst case scenarios as shown in Fig. 4. As per the results of the pit optimisation, the selection of the optimal pit can be based on various criteria such as: NPV, stripping ratio and cut-off grade. In this work, NPV was used to choose the optimal pit. The highest NPV was recorded as Pit 36 in the best case scenario.

The best case scenario consists of mining out the smallest pit, and then mining out each subsequent pit shell from the top down, before starting the next pit shell; the worst case scenario consists of mining each bench completely before starting on the next bench. A pit shell is the outline formed as a result of a pit optimisation which contains the blocks worth mining (Anon., 1998).

2.2.2.6 Optimal Pit Selection

Pit 36 was selected since it had the highest NPV @10% of \$338 599 114 from the best case scenario. A sensitivity analysis of the NPV was done by varying the mining cost and the price of gold. Table 5 shows an incremental pit value analysis that shows that the NPV increases gradually to Pit 36 and then starts reducing at Pit 37.

Table 5 Incremental Pit Value Analysis

Pit No.	NPV (\$)	Increase in NPV (\$)
32	338 492 585	0
33	338 545 737	53 152
34	338 578 554	32 817
35	338 591 815	13 261
36	338 599 114	7 299
37	338 592 058	-7 056
38	338 579 380	-12 678

2.2.2.7 Sensitivity Analysis

The base case figures for these parameters were varied from -50% to 50% so as to check the effect of the changes of mining cost (all other parameters remaining constant) and gold price (all other parameters remaining constant) on the NPV.

The results of the analysis are shown in Fig. 5. From the graph, the NPV is very sensitive to changes in gold price but marginally sensitive to the changes in mining cost.

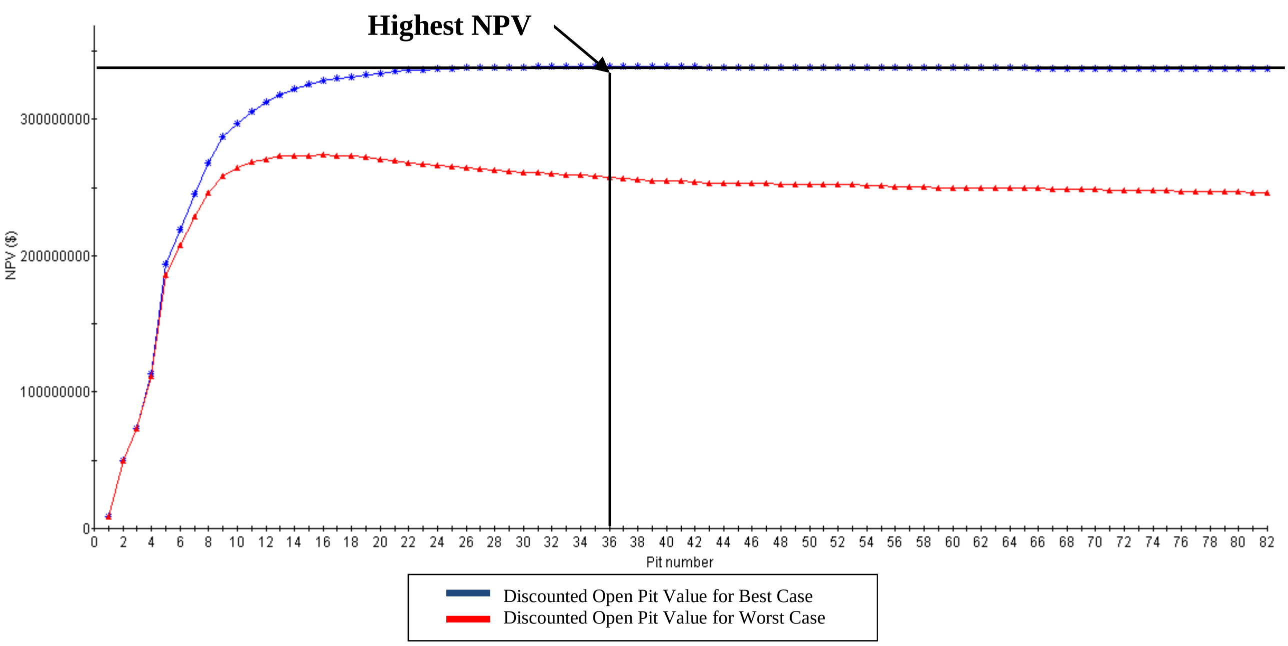

Fig. 4 NPV vs. Pit Number

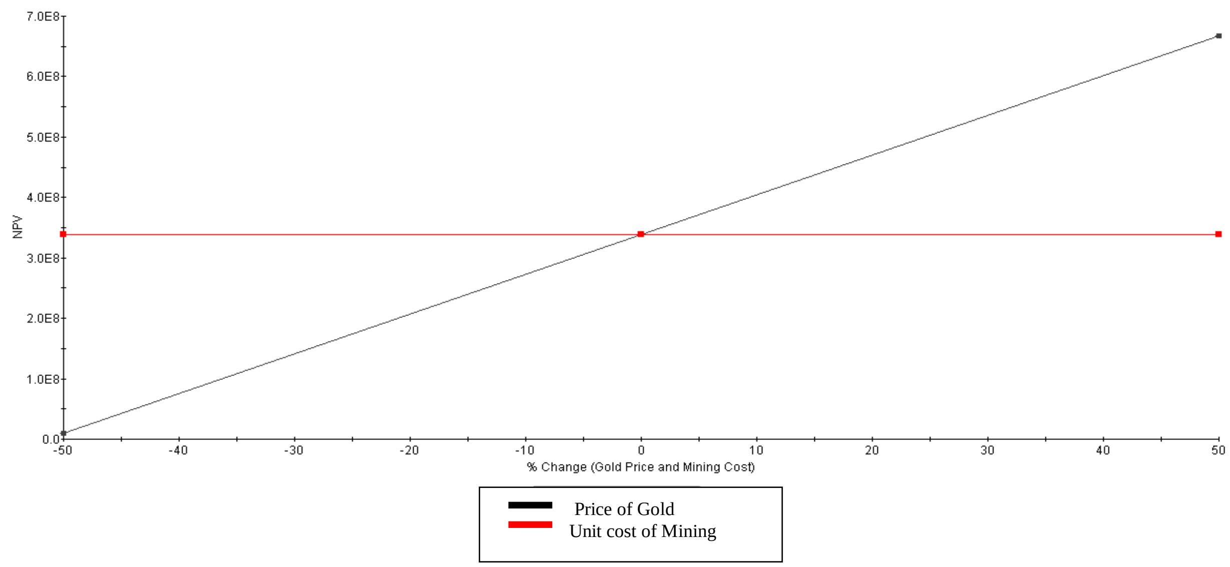

Fig. 5 Sensitivity Analysis Graph

The optimal outline (Pit 36) containing the results file was exported from Whittle to Surpac software for pit design. Fig. 6 shows the optimal pit shell that was exported to Surpac for design.

2.2.3 Detailed Pit Design Using Surpac

The design involved the inclusion of safety berms and haul roads in the optimal pit that was generated by Whittle software. Designing of the pit was attained by employing the pit design tools in the application menu of the design window of the Surpac software.

The design parameters employed are summarised in Table 6. The selection of the parameters was based on the overall slope angle that keeps the wall slope stable and safe. Another criterion was the width and the gradient of the haul roads and the bench height, controlled by the selected equipment.

Table 6 Parameters Employed in Pit Design

Parameter	Value
Ramp and Haul Road Width (m)	20
Ramp Gradient (%)	10
Final Slope Angle (degrees)	45
Face Angle (degrees)	70
Bench Height (m)	10
Bench Width (m)	20
Berm width (m)	6.5

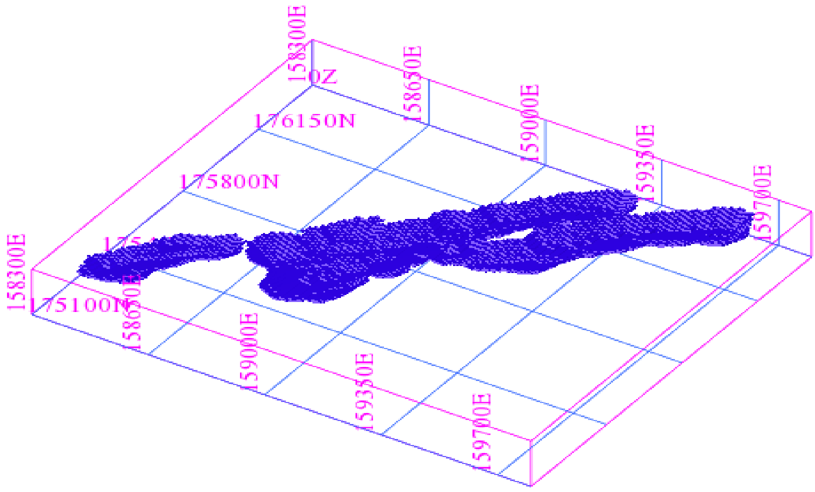

Fig. 6 Whittle Optimal Pit Shell

Two pits were designed, one with all-cut ramp and the other with circular ramp. The design process was the same for the two pits apart from defining the type of ramp. The design started from the pit bottom upwards to allow enough operational space at the pit bottom.

The following steps were followed during the design process:

(i) Creation of a pit base string;

(ii) Creation of ramps;

(iii) Creation of crest and toe strings; and

(iv) Intersection of the pit and topography.

2.2.3.1 Creation of a Pit Base String

The lowest elevation of the pit contours was checked so as to locate the base of the pit. The pit base string was created using the optimised pit contour as a guide. The contour was expanded to include the ore blocks while ensuring that the design was close to the contours of the optimised pit. The total area of the pit base was 148 390 m^2 for both pits. Limits were set up so that consecutive contours could be considered when planes were moved onward for designing.

2.2.3.2 Creation of Ramps

Following the establishment of the pit base string, a ramp was then created to connect to the next bench. The width of the ramp was set at 20 m to allow for the proposed 3.7 m wide dump trucks, and give allowance for space between the edges of the ramp and the trucks. A gradient of 10% was set for the ramps.

2.2.3.4 Creation of Crest and Toe Strings

The crest string generated from the creation of the ramps was used in making the berm at that elevation. This crest string acted as the toe string for the next bench. From this string, a ramp was then created to link the bench above. The design process of toe, ramp and crest was then carried out from bench to bench to the surface.

2.2.3.5 Intersection of the Pit and Topography

When the pit was well designed to the surface, a DTM was then created for the designed pit which was then intersected with the topography DTM. A boundary string was created to define the intersection of topography and the pit. During the intersection the surfaces that were protruding above the topography were trimmed off.

3 Results and Discussion

Fig. 7 shows the final pit that was designed with the all-cut ramp while Fig. 8 shows the final pit that was designed with the circular ramp.

A report of the volume of the optimal Whittle pit shell, pit designed with all-cut ramp and pit designed with circular ramp was generated and the results are shown in Tables 7, 8, and 9 respectively. From these tables, it is evident that the total tonnage of each of the two designed pits has increased as compared to the Whittle optimal pit. The pits designed with all-cut ramp and circular ramp deviated from the Whittle optimal pit by 13 % and 9.7 % respectively. These can be attributed to the fact that the pit bottoms of the designed pits were enlarged to allow sufficient room for equipment to manoeuvre. Another reason was the addition of the berms and the ramps during the design which was not included in the optimal pit from Whittle.

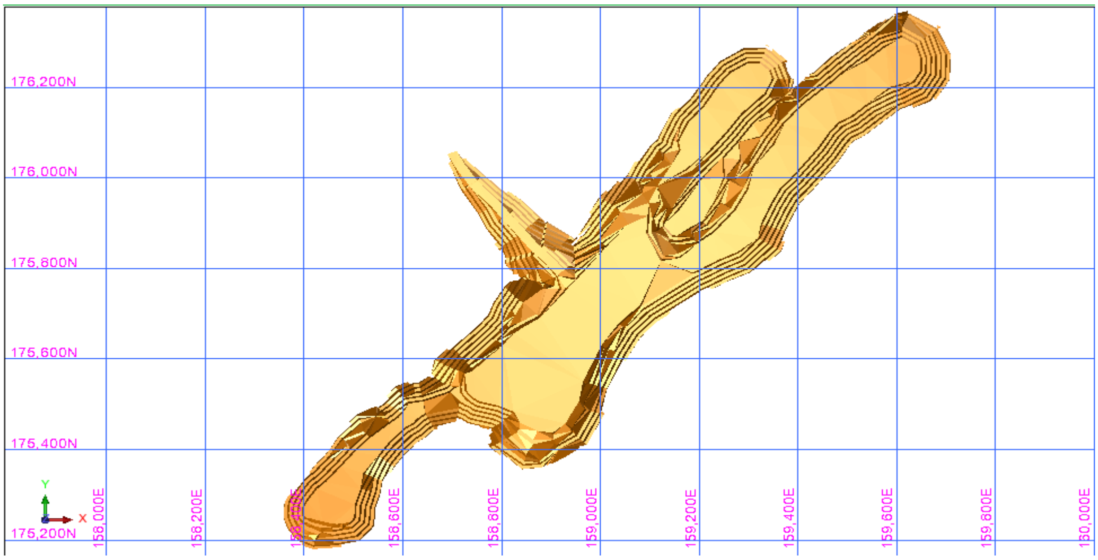

Fig. 7 Final Pit Design with All-Cut Ramp

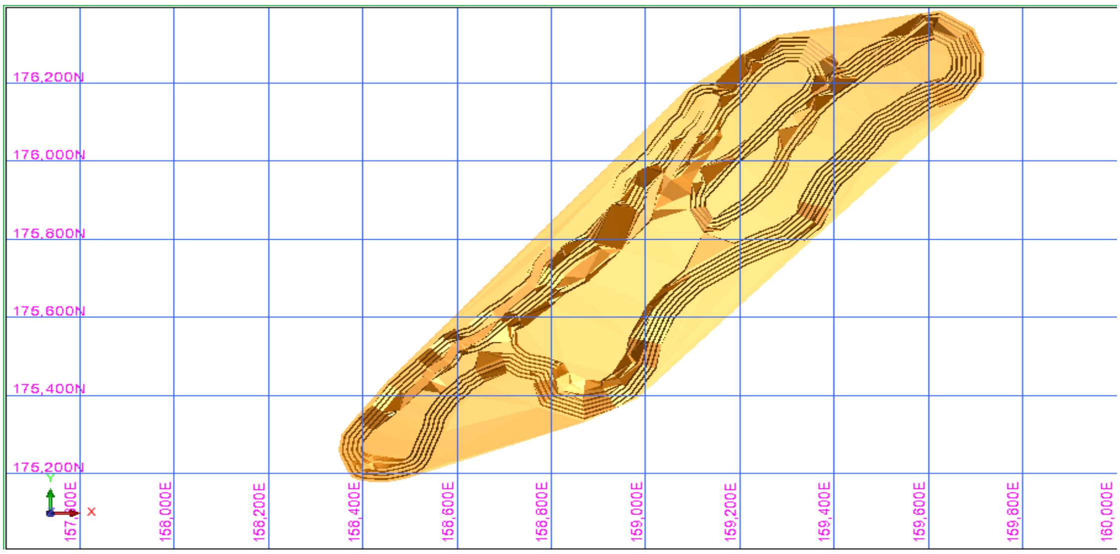

Fig. 8 Final Pit Design with Circular Ramp

Comparing the two pits designed, one with the all-cut ramp and the other with circular ramp, from Tables 8 and 9 respectively, it is clear that the pit designed with circular ramp had higher expected revenue and lower stripping ratio than the pit with all-cut ramp. The pit designed with all-cut ramp had a stripping ratio of 0.996:1, while the pit designed with circular ramp had 0.943:1. The difference was brought about by the volume of waste that was to be mined out for the all-cut ramp to get to the surface. The all-cut ramp extended to a distance of about 350 m from the outer wall of the pit thus covering a large area that could be used for other purposes. The pit designed with the circular ramp was therefore chosen for the Mpeasem Gold Mining Project.

Table 7 Whittle Optimal Pit Results

	Volume (m^3)	**Tonnage (t)**	**Av. Grade (g/t)**
Ore	7 763 500	21 194 355	1.557
Waste	5 452 500	14 707 875	0.004
Total	13 216 000	35 902 230	
Stripping Ratio:	0.65:1		

Table 8 Pit Design with All-Cut Ramp Results

	Volume (m^3)	Tonnage (t)	Av. Grade (g/t)
Ore	7 424 610	20 269 185	1.543
Waste	7 397 500	20 195 175	0.005
Total	14 822 110	40 464 360	
Stripping Ratio:	0.996:1		
Expected Revenue:	$955 227 452.40		

Table 9 Pit Design with Circular Ramp Results

	Volume (m^3)	Tonnage (t)	Av. Grade (g/t)
Ore	7 428 317	20 279 306	1.549
Waste	7 008 318	19 132 708	0.005
Total	14 436 635	39 412 014	
Stripping Ratio:	0.943:1		
Expected Revenue:	$959 420 709.70		

4 Conclusions

The Surpac software has all the features that facilitate the block modelling of a deposit, and the detailed design of an open-pit incorporating benches, berms and ramps. The software is menu driven, and thus easy to understand and use. The Whittle software uses the block model prepared in Surpac software and applies Lerchs-Grossmann algorithm to optimise the pit within the block model. The input parameters required during the optimisation include: the block model, technical parameters such as overall slope angle, and economic parameters such as the mining and processing costs. Surpac and Whittle software combine to form a useful tool for open pit optimisation and design.

The MGMP deposit extends in meters from 158350E to 159653E, and 175180N to 176352N. It has undergone intense weathering resulting in the formation of oxidised gold deposit up to about 50 m in depth with an average width of about 25 m dipping at 80^{o}.

The block model of the deposit prepared using Surpac software gives 22 784 580 tonnes of ore at an average grade of 1.533 g/t.

The optimal pit contains 21 194 355 tonnes of ore at an average grade of 1.557 g/t; has a stripping ratio of 0.65:1 and an NPV @10% IRR of $338 599 114. The NPV is very sensitive to changes in gold price but marginally sensitive to changes in mining cost.

The pit designed with the circular ramp is preferred over the pit designed with all-cut ramp for mining the deposit since it has a higher expected revenue and lower stripping ratio. It gives 20 279 306 tonnes of ore at an average grade of 1.547 g/t, has a stripping ratio of 0.943:1 and a total expected revenue of $959 420 709.

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