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Geological resource modelling and mine planning of a surface limestone deposit

As the mines are growing bigger the need for the advancement has also increased. The computer aided mine planning and design techniques have come as an advantage for mining industry. This project aims to exhibit the implementation of computer aided mine planning and design techniques in mining industry which gives more accuracy and reliability of mine plan. Opencast mine planning is a multi-parameter optimization problem which requires simultaneous solution. This project emphasises on the optimized planning of limestone mine where the ore is categorized into lithologies on the basis of percentage of CaO present. It uses software such as SURPAC for geological modelling, block modelling, ore reserve estimation using geostatistical model and pit design. The estimation is done using kriging which shows that the percentage of CaO varies from 30.24 % to 47.05% which helps in determining the minable ore. It also aims at the optimization of various techno-economic parameters which play vital role in mine planning and design aspects.

Keywords: *SURPAC, kriging, geological modelling, reserve estimation, block model*

1. Introduction

As the mines are becoming bigger and with the improvement in technology offered in mining sector the optimization of mining parameters has become more accurate and precised. Proper execution of mine plan is required to achieve the production target. Better utilization of resources can be done by proper implementation of mine plan during the starting phase. Conventional mine planning methods for reserve estimation are very tedious and time taking process. Software such as SURPAC, MINESCHED, WHITTLE has made mining practices more efficient from all aspects of mining industry (Gallagher, 2001). Opencast mine planning is required for assessing the total ore reserve and grade value of the deposit. Scheduling is done time to time basis for fulfilling the target from the estimated quantity of ore reserve. Mine scheduling is responsible for where to extract the ore for achieving the market demand. Scheduling is done according to the current requirement of the management. Opencast mine planning is done by dividing the whole ore blocks into smaller blocks and sub blocks. During block model appropriate depth is selected for designing the pit. Designing of pit is done by taking the suitable stripping ratio in order to make the project economic.

This paper aims at the modelling of a limestone ore opencast mine using SURPAC software which will help in 3D visualization of deposit consisting of 156 boreholes. Ore reserve estimation is done using ordinary kriging process with help of semi-variograms which considers the spatial relationship along the deposit (Moharaj and Wangmo, 2014). Ultimate pit is also designed using the various tools provided by SURPAC.

2. Methodology

The formation of geological database, ore reserve estimation and designing of pit is carried out with the help of SURPAC. The work is done on 156 boreholes gathered from a limestone ore deposit. This work is divided into mainly three steps:

(i) Creation of geological database.
(ii) Formation of block model and ore reserve estimation using ordinary kriging method.
(iii) Generation of ultimate pit using slice plans generated by SURPAC.

2.1 Creation of geological database

To establish the geological database, we collected the data of about 156 boreholes with samples consisting of various percentages of CaO, Al_2O_3, SiO_2, and Fe_2O_3. The data is categorized into various lithologies. This data is arranged in the form of tables as required in SURPAC. It is categorized into mainly four tables namely assay, geology,

Table 1: Part of Collar Table

Hole Id	X(m)	Y(m)	Z(m)	Max depth(m)	Hole path
CBH03	1736427	226560	246.2	50	Vertical
CBH04	1736426	226736	246.9	47	Vertical
CBH05	1736398	227136	248.7	50	Vertical
CBH07	1736269	226130	242.9	50	Vertical
CBH08	1736227	226298	244.6	50	Vertical
CBH09	1736241	226496	246.5	40.5	Vertical

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Table 2: Part of survey table

Hole Id	Depth (m)	Dip (^{0})	Azimuth
CBH03	50	-90	0
CBH04	47	-90	0
CBH05	50	-90	0
CBH07	50	-90	0
CBH08	50	-90	0
CBH09	40.5	-90	0

Table 3: Part of Assay Table

Hole Id	Depth from (m)	Depth to (m)	SiO_2 (%)	Al_2O_3(%)	Fe_2O_3(%)	CaO (%)
CBH03	0	2	16.63	2.45	1.4	43.68
CBH04	0	2	19.87	1.43	1.12	42.84
CBH05	0	2	10.56	0.82	0.69	48.16
CBH07	0	1	11.43	1.12	0.67	47.88
CBH08	0	2	9.76	0.92	0.52	49.14
CBH09	0	2	15.62	1.43	0.39	45.5

Table 4: Part of geology table

Hole Id	Depth from (m)	Depth to (m)	L code
CBH03	0	2	9
CBH04	0	2	10
CBH05	0	2	4
CBH07	0	1	4
CBH08	0	2	3
CBH09	0	2	8

survey and collar (Sarkar and Roy, 2005). The following tables below show the structural arrangement of various tables.

These tables are most important part of the formation of geological database. Creation of database takes place by importing this data tables into SURPAC and validation of data takes place where the data input structure is inconsistent data and is rejected and a geological database is formed (Sahoo and Pal, 2017).

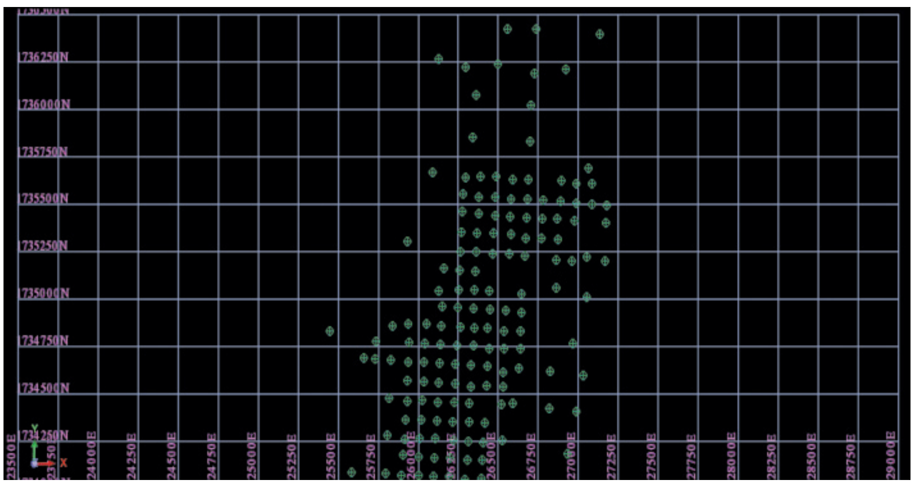

Fig.1 Drill hole layout

It is the basic prerequisite for the formation of 3D geological model (Torabi and Choudhary, 2017). Once the database is formed the drill hole layout can be visualized in 3D and various styles can be assigned to the various lithologies present. The topography of the surface can be generated using the drill hole layout.

2.2 Formation of 3D geological model

The formation of geological database is the first step for the formation of geological 3D model. To form a 3D geological model borehole sections are created using various options available in SURPAC; mainly it has northing, easting, graphical and best fit method (Sinha et al., 2017). Once the sections are created, they are digitized according to their lithologies using different string number so as to distinguish between them and after completion of section various lithologies are separated from each section and solid is formed for each lithologies present. Solid can be formed using various options available in SURPAC such as joining of segment, extrude, joining of one segment to two or many. Combination of solids of all the litho will give a complete 3D visualization of deposit (Roy and Sarkar, 2005).

2.2.1 Ore reserve estimation

Ore-reserve estimates are based upon the results of exploration and development and analyses of the samples derived therefrom. Unless a deposit is fully developed (and even then, to a lesser degree), certain assumptions have to be made regarding the continuity and grade of ore between exposed faces or drill holes that have been sampled. Ore-reserve estimates include the determination of tonnages of ore and average grade or value per tonne. Since the grade or content of valuable metal establishes the difference between rock that may and may not be classed as ore, tonnage cannot be estimated without considering the question of grade.

Formation of block model, analysis of data and semi variogram are the prerequisite of ore reserve estimation. A composite data string file of various lithos is formed and analyzed and is used as an input parameter for semi-variogram analysis (Krige, 1951). A block model is prepared using the extent of the area under the mining lease. Constraint files of all the litho's are generated respectively and attributes to the model is defined such as CaO, SiO_2, Al_2O_3, Fe_2O_3, sg (specific gravity), litho (lithology) and pp (partial percentage) with desired data types (Stone and Dunn, 1996).

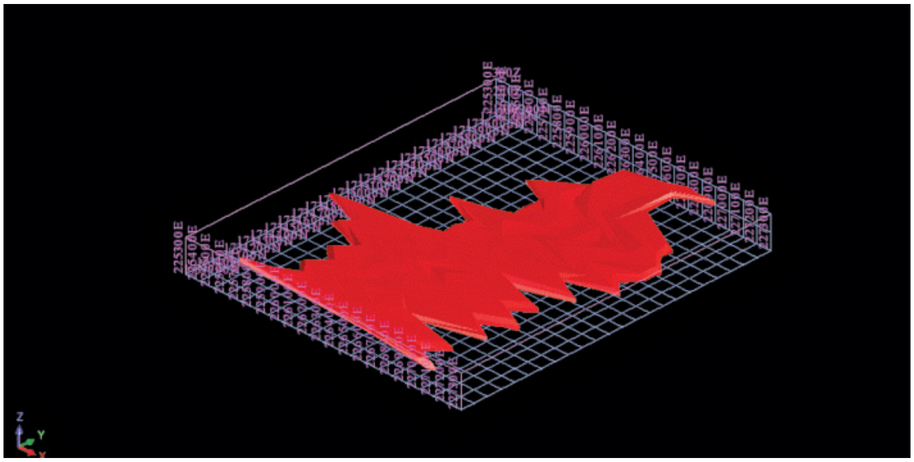

Fig.2 3D Model of a deposit

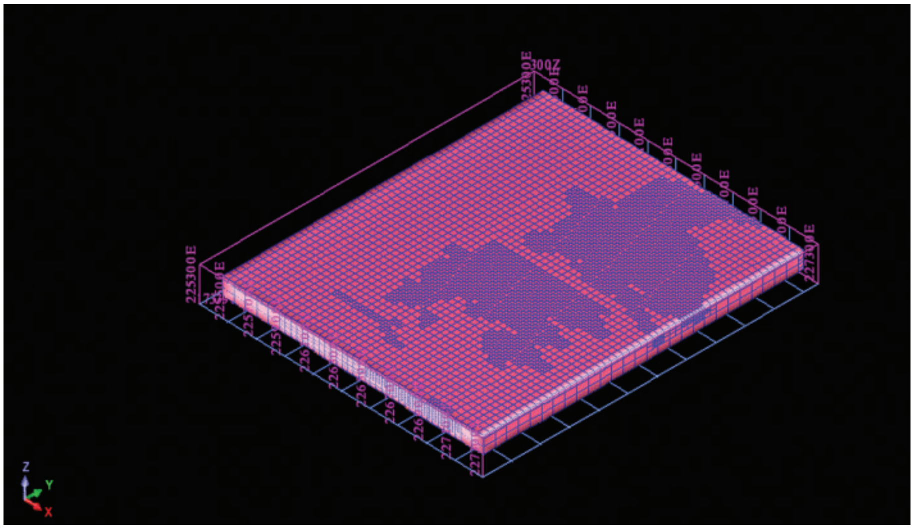

Fig.3 Block model with solid ore

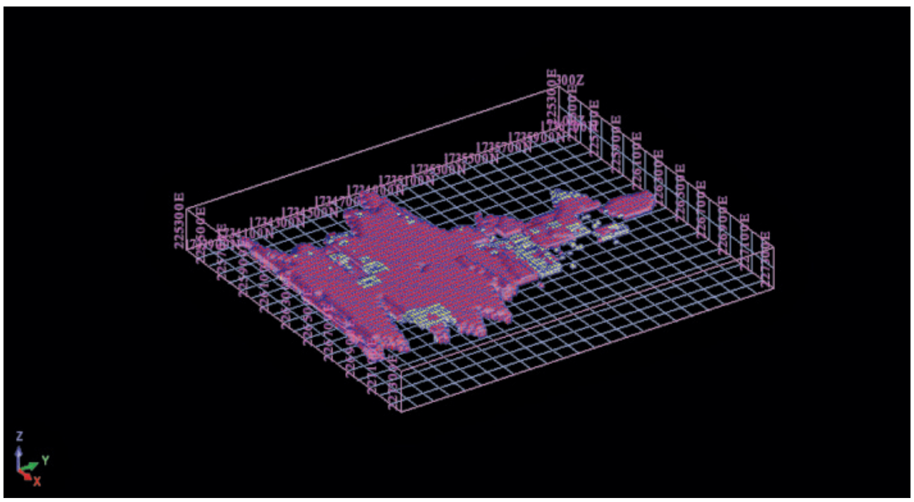

Fig.4 Solid ore block model constrained with attributes by colors

Specific gravity and lithology are assigned values using the assign value function of block model in SURPAC where the value of specific gravity varies from 2.6 to 2.8 for a limestone ore deposit. Partial percentage is the measure of the part of block in deposit or what part of block is in air. (Huang et al., 2011). Value of partial percentage can be calculated using partial percentage function of block model function in SURPAC and it varies from 0 to 1. Fig.3 shows the solid ore which is merged within the block model.

Once the semi-variogram is formed validation of variogram is done where the mean of errors should be nearly equal to 0, variance and average kriging variance should be equal and the percentage of errors within two standard deviations should be nearly 95% (Fytas et al., 1990). If all these conditions are satisfied, then the variogram is said to be validated and this variogram can be used as input for the process of estimation using various functions available in SURPAC. In this paper, we use the method of ordinary kriging techniques for the estimation of the reserve where the validation and variogram files are used as inputs and estimation for CaO, SiO_2, Al_2O_3, Fe_2O_3 is done (Vaan and Guibal, 1998)

Various colours in the above block model show the variation in the percentage of CaO present in the deposit. Estimation of the deposit shows that the % of CaO varies from 30.24 to 47.05, % of SiO_2 varies from 12.85 to 35.72, % of Al_2O_3 varies from 1.39 to 4.36 and % of Fe_2O_3 varies from 0.72 to 3.26. The value of CaO less than 30% is considered as waste and higher value of other components is also rejected.

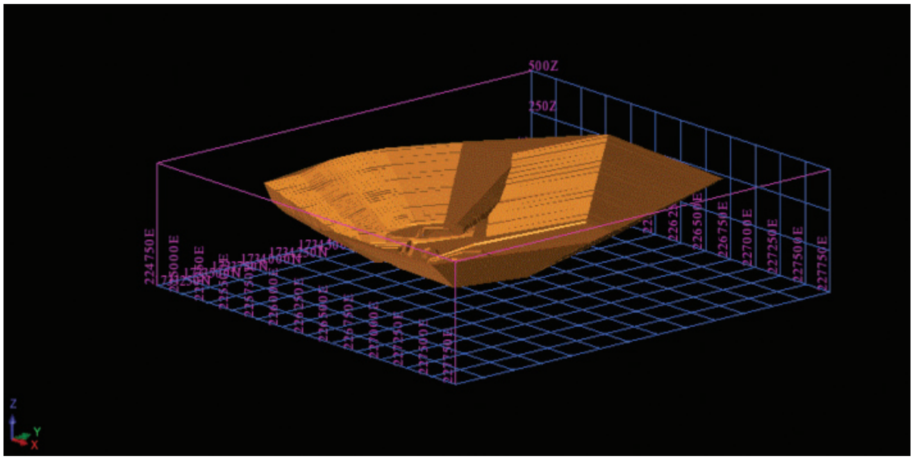

Fig.5 Pit design

2.3 Ultimate pit design

Optimum pit design plays a major role in all stages of the life of an open pit mine. At all stages there is a need for constant monitoring of the optimum pit to facilitate the best long-term, medium term and short term mine planning and subsequent exploitation of the reserve. The optimum ultimate pit of a mine is defined to be that contour which is the result of extracting the volume of material which provides the total maximum profit whilst satisfying the operational requirement of safe wall slope. The ultimate pit limit gives the shape of the mine at the end of its life. Usually the contour is smoothened to produce the final pit outline.

Once the ore estimation is done the next aim is to generate ultimate pit. Slice plan is the prerequisite for the modelling of ultimate pit. It is done by using sections function provided in the block model of SURPAC. Slice plans are obtained at an interval of 10 m along the Z axis. Each slice is taken and pit is designed by expanding the bench by height. Slope gradient is set to 700 and the berm width is taken as 10 m (Agrawal, 2012). Haul road is the major concern while designing a pit position of the ramp should be chosen by considering all the parameter, width of the haul road should take by considering all the mining parameter (Wang et al., 2011).

3. Results and conclusion

For any exploration data, SURPAC can be used to design an ultimate pit. The study shows that after the formation of geological model the volume of ore is 87623051 tonnes with an average grade of 45.95%. The final pit design has a total volume of 126582943 tonnes where the volume of ore is 33106818 tonnes and the volume of waste is 93476125 tonnes. Overall stripping ratio is computed to be 2.82:1

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