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Ultimate Pit Limit Optimization Of Opencast Mine Using Surpac Software

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ABSTRACT

This study focuses on optimizing the Ultimate Pit Limit (UPL) for opencast limestone mining using SURPAC software. The research aims to demonstrate the advantages of integrating advanced software in the mine planning process, specifically for optimizing pit design and improving resource recovery. By utilizing geological data, including borehole surveys, assay results, and lithological information, a 3D block model was developed, and various optimization algorithms were applied to determine the most economically viable pit boundaries. The study compares traditional manual methods with modern software-based approaches, showcasing the significant reduction in time and error. SURPAC's integration of Lerchs-Grossmann and other algorithms allowed for more accurate mineable reserve estimation, enhanced safety measures, and improved environmental sustainability by minimizing waste removal and optimizing resource extraction. This research highlights the potential for modern mine planning software to transform the efficiency, safety, and profitability of opencast mining operations.

Keywords – Ultimate Pit Limit, SURPAC software, opencast mining, resource optimization, mine planning, Lerchs-Grossmann algorithm, limestone mining.

1. INTRODUCTION

Opencast mining, particularly in the extraction of limestone, requires precise planning to maximize resource recovery, minimize operational costs, and ensure safety. Traditional manual methods of mine planning, which rely on tedious calculations and are prone to human error, are increasingly being replaced by advanced computational techniques. These methods offer higher precision, faster results, and the ability to integrate complex datasets, making them crucial for large-scale mining operations. The use of specialized mine planning software such as SURPAC has revolutionized the mining industry by providing tools for geological modelling, resource estimation, pit optimization, and scheduling.

The Ultimate Pit Limit (UPL) optimization is a fundamental process in opencast mine planning. It defines the boundaries of the mining pit, considering geological, economic, and operational constraints, and helps determine the most profitable extraction strategy. Traditionally, UPL was calculated using manual methods that were time-consuming and often resulted in suboptimal pit designs. However, with the integration of advanced algorithms like Lerchs-Grossmann, mining software now enables the generation of optimized pit designs that maximize resource extraction while minimizing waste. This paper focuses on the use of SURPAC software for UPL optimization in an opencast limestone mine. The primary objective is to assess the effectiveness of SURPAC in creating a detailed and optimized pit design, utilizing geological data, economic parameters, and operational constraints. The research also aims to compare the results of the software-based UPL optimization with traditional methods, highlighting the advantages in terms of accuracy, cost-efficiency, and time.

By optimizing the UPL, this study contributes to the efficient management of resources, cost reduction, and enhanced safety in mining operations, providing a foundation for long-term planning and sustainability in the mining sector.

2. LITERATURE REVIEW

The optimization of the Ultimate Pit Limit (UPL) is a critical aspect of mine planning in open-pit mining, influencing both resource extraction and economic viability. Over the past several decades, numerous advancements in mining technologies and optimization algorithms have enhanced the accuracy, efficiency, and cost-effectiveness of pit design. This literature review examines the evolution of techniques and methods used in UPL optimization, with a specific focus on the use of modern software tools such as SURPAC.

Whittle (1990) is widely credited with developing one of the first algorithms for open-pit optimization, which became a cornerstone in the mining industry. His work on the Lerchs-Grossmann algorithm paved the way for the development of more advanced computational techniques, enabling more efficient and accurate determination of UPL. The Lerchs-Grossmann algorithm remains one of the most widely used methods for optimizing pit design, as it helps identify the most profitable pit boundaries while adhering to geotechnical and economic constraints.

Achireko and Frimpong (1996) introduced an algorithm that integrates random field characteristics, including ore grade, market price, and geological variability, to improve the accuracy of UPL calculations. Their approach considered multiple layers of ore properties and focused on optimizing the pit design by categorizing blocks based on economic values, enhancing the efficiency of the final pit design.

Sevim and Lei (1998) expanded on the traditional methods by incorporating cut-off grades, mining rates, and the sequence of mining operations into the pit design. Their work emphasized the interconnected nature of these parameters, where a change in one factor (such as the cut-off grade) influences the overall economic value and mine planning. This study highlighted the importance of considering not only geological factors but also market and operational factors when designing an optimal pit. In recent years, advancements in software tools such as SURPAC have revolutionized UPL optimization. SURPAC is a comprehensive mine planning software that allows for detailed geological modelling, resource estimation, and optimization of pit designs.

Akbari et al. (2008) highlighted the application of SURPAC in surface mining, demonstrating its ability to integrate geological, geotechnical, and economic data into a cohesive model for optimizing the ultimate pit. Their work showcased the efficiency of SURPAC in handling complex datasets and producing accurate mineable reserves and optimized pit designs.

Torabi and Choudhary (2017) explored the use of block modelling in combination with SURPAC to enhance mine planning. By applying the inverse distance weighting method for grade interpolation, their study achieved high accuracy in estimating ore body characteristics. This method, when combined with SURPAC's capabilities, allowed for the creation of optimized pit designs that minimized waste and maximized resource extraction.

Mbah et al. (2020) emphasized the role of statistical analysis in UPL optimization, incorporating ecological costs and operational constraints into the decision-making process. Their research highlighted how modern software tools can provide more sustainable and economically viable pit designs by accounting for factors such as slope stability, environmental impact, and market price fluctuations.

Ares et al. (2022) explored the floating cone algorithm, an alternative to Lerchs-Grossmann, which offers enhanced precision and faster computation. While Lerchs-Grossmann remains the standard for UPL optimization, the floating cone method is gaining traction due to its competitive outcomes, especially in cases involving marginally profitable blocks.

Xu, Zhu, Ye, Gu, Wang, Zhao & Liu (2024) presents an optimized Ultimate Pit Limit (UPL) method for open-pit coal mining that integrates ecological, safety, and economic considerations. By analyzing slope angle variations, the study shows a significant increase in economic benefits, with a 9.54M USD profit rise per 1° slope increase, while also addressing ecological costs. It highlights that in semi-arid regions, environmental costs can exceed 20% of economic gains, and steeper slopes lead to diminishing returns due to higher ecological and slope maintenance costs. The findings emphasize the balance between economic gains and sustainability.

In summary, the literature demonstrates a clear shift from traditional manual methods to sophisticated software-based solutions for UPL optimization. Tools like **SURPAC** have become indispensable in modern mining, offering not only improved accuracy and efficiency but also the ability to integrate multiple variables—geological, economic, and environmental—into the optimization process. This transition underscores the importance of adopting advanced technologies to stay competitive in the evolving mining industry.

3. SIGNIFICANCE OF PROJECT

The significance of this project lies in its potential to revolutionize the approach to opencast mine planning using advanced computational tools like SURPAC. By integrating geological, economic, and operational data into the mine planning process, this study aims to provide a more efficient, accurate, and cost-effective approach to Ultimate Pit Limit (UPL) optimization, which is critical for enhancing resource extraction and ensuring long-term profitability. The key aspects of its significance are outlined below:

1. **Resource Optimization**
   The primary objective of UPL optimization is to maximize the resource extraction while minimizing waste. This research leverages SURPAC's powerful modelling and optimization capabilities to accurately determine the boundaries of the mining pit, ensuring that the most valuable sections of the deposit are prioritized for extraction. The optimization of UPL helps reduce waste rock removal, thereby improving the strip ratio and ensuring the most efficient use of resources, which is critical for sustaining mining operations in the long term.

2. **Economic Viability**
   The success of any mining operation depends on its economic viability. The Net Present Value (NPV) of a mine is significantly influenced by the accuracy of its pit design. By using modern optimization algorithms and incorporating real-time data into the mine planning process, the project ensures that the pit design aligns with market conditions, minimizing operational costs while maximizing the extraction of valuable minerals. This research aids in achieving a cost-effective mine design that enhances the overall profitability of the mining operation.

3. **Environmental Impact**
   Sustainable mining practices are becoming increasingly important due to growing environmental concerns. The optimization of the UPL using advanced software allows for more efficient pit design, reducing the volume of overburden and waste generated during mining operations. Additionally, it helps minimize the disturbance to surrounding ecosystems by focusing on economically viable zones, which in turn reduces the environmental footprint of mining operations. This project, therefore, contributes to eco-friendly mining practices by minimizing waste generation and overburden removal.

4. **Safety and Operational Efficiency**
   Safety is paramount in mining operations, and a well-designed pit plays a crucial role in minimizing risks. Through geotechnical analysis and slope stability modelling, SURPAC facilitates the creation of safe pit slopes, reducing the risk of slope failures and accidents. Furthermore, this research enhances operational efficiency by optimizing the sequence of mining operations, ensuring that the fleet of equipment is utilized effectively and reducing idle time for shovels and dumpers. This leads to more streamlined and safer mining operations.

5. **Long-Term Mine Planning**
   Effective mine planning is essential for ensuring that a mining project remains viable and sustainable over its operational life. The optimization of UPL allows for better long-term planning by providing accurate estimates of mineable reserves, production rates, and pit design changes over time. This approach ensures that the mine's resources are exploited efficiently throughout its life cycle, aligning with both operational goals and financial sustainability.

6. **Regulatory Compliance**
   Mining projects must comply with various local and international regulations regarding resource extraction, environmental impact, and worker safety. The use of SURPAC in this study ensures that the UPL design adheres to geotechnical constraints, slope stability requirements, and environmental guidelines, making the mine design

compliant with legal and regulatory frameworks. This research, therefore, aids in securing permits and maintaining regulatory compliance throughout the mine's operational life.

SURPAC is a comprehensive mining software tool that integrates a wide array of features specifically designed for geological modelling, mine planning, and resource estimation. The key features of SURPAC that contribute to the success of this project are outlined below:

7. **Geological Modelling and Block Modelling**
SURPAC's ability to create 3D geological models and block models plays a critical role in accurate mine planning. The software allows users to visualize and interpret geological data, providing a spatial representation of ore bodies and waste materials. This feature is essential for determining the minable reserves and establishing an accurate block model for UPL optimization. By converting borehole data into a digital format, SURPAC provides a detailed view of ore distribution, which is fundamental to the effective design of mine pits.

8. **Ultimate Pit Limit (UPL) Optimization**
SURPAC incorporates advanced optimization algorithms, such as the Lerchs-Grossmann method, which is widely recognized for its efficiency in determining the optimal pit boundaries. The software allows for the integration of various mine parameters (e.g., stripping ratio, grade, market conditions, and geotechnical constraints) to ensure that the pit design maximizes profit while minimizing waste. The UPL optimization capability of SURPAC makes it an invaluable tool in this project, ensuring the most economically viable pit design while adhering to operational and environmental constraints.

9. **Slope Stability and Geotechnical Analysis**
The geotechnical analysis features of SURPAC enable users to model and analysed slope stability, ensuring that the pit design adheres to safety standards. The software supports the creation of safe pit slopes by considering factors like rock strength, jointing patterns, and the effects of mining operations on the surrounding environment. This capability is particularly significant in enhancing operational safety, reducing the risk of slope failures, and improving the long-term stability of mining operations.

10. **Resource Estimation and Grade Interpolation**
SURPAC includes powerful tools for resource estimation, allowing users to apply various methods such as kriging and inverse distance weighting for grade interpolation. This functionality is essential for accurately estimating the average grade of the deposit, which directly influences the UPL optimization process. By accurately estimating grade distribution, SURPAC ensures that the most profitable sections of the deposit are prioritized for extraction, contributing to higher resource recovery and better economic outcomes.

11. **Production Scheduling and Optimization**
SURPAC offers production scheduling tools that help mine planners design efficient extraction sequences. By integrating data on ore grade, stripping ratio, and equipment availability, the software facilitates the creation of a mining schedule that minimizes operational costs while maximizing resource extraction. This feature ensures that mining operations are optimized for cost-efficiency and meet production targets, contributing to the overall profitability of the mine.

12. **Visualization and Reporting**
The software's ability to generate detailed 3D visualizations and cross-sectional views allows mine planners to assess different pit design scenarios and better understand complex geological structures. SURPAC's reporting tools provide comprehensive insights into the results of pit optimization, resource estimation, and scheduling. These visual and analytical outputs are crucial for communicating results to stakeholders, improving decision-making processes, and ensuring regulatory compliance.

4. METHODOLOGY

The field and laboratory investigations are fundamental to the accuracy and reliability of the data used for mine planning, particularly for UPL optimization. This section outlines the steps involved in the collection of geological data, field analysis, and the laboratory procedures necessary to model the limestone deposit and optimize the pit design using SURPAC software.

1. Study Area and Geological Background

The field investigations were conducted at the Daroli Limestone Mine, located approximately 24 km from Udaipur city, Rajasthan, India. The geographical coordinates for the mine are Latitude: N 240°33’40” to N 240°37’28” and Longitude: E 730°55’07” to E 730°56’30”. The study area lies within the Archean Crystalline Complex, with limestone deposits belonging to the Railo series. The geological characteristics of the area, as detailed in the previous sections, include: The presence of pegmatite and quartz veins traversing the limestone.

A medium to coarse-grained crystalline limestone with varying silica content. Schist and quartzite layers that influence ore body continuity.

2. Field Work

Fieldwork in this study primarily focused on the collection of borehole data, geological mapping, and surveying. The key data collected in the field included:

2.1 Borehole Data: Borehole logs from 99 boreholes were used to gather critical geological and assay information (e.g., depth, lithology, grade, and mineral composition).

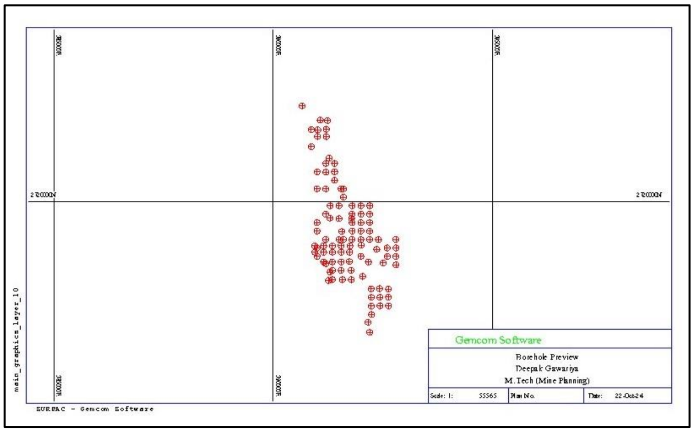

Figure 2.1 Borehole Location Plan

2.2 Survey Data: Detailed survey data, including the location (X, Y, Z coordinates) of each borehole, and the dip and azimuth of boreholes were collected to ensure accurate modelling of geological features.

2.3 Geological Mapping: Field mapping provided insights into the stratigraphy, geological formations, and fault zones that may affect the pit design and resource estimation. The field investigations also included a study of local geology, mineral distribution, and the influence of structural features (e.g., joints and faults) on the geotechnical properties of the limestone deposit.

3. Laboratory Investigations

Laboratory investigations were conducted to characterize the physical and chemical properties of the limestone deposit and validate the data used in the modelling process. The laboratory work focused on:

3.1 Chemical Composition: Assay samples from boreholes were analysed in a laboratory to determine the mineral content (e.g., CaO, SiO_2, Fe_2O_3, MgO), which are critical for grade estimation and resource modelling.

3.2 Rock Mechanics Testing: Laboratory tests were conducted to assess the mechanical properties of the limestone, including compressive strength, tensile strength, and elastic modulus. These properties are crucial for slope stability analysis during the UPL optimization process.

3.3 X-Ray Diffraction (XRD): The XRD analysis helped in identifying the mineralogical composition of the limestone, particularly the content of calcite, quartz, and other minerals that might influence ore quality and processing.

3.4 Moisture Content and Bulk Density: Laboratory tests on the moisture content and bulk density of the limestone helped in calculating the volume-to-tonnage conversion and estimating minable reserves.

4. Data Validation and Pre-Processing

The data obtained from the field and laboratory investigations were validated to ensure consistency and accuracy. The steps involved in the data pre-processing included:

4.1 Error Checking: Inconsistencies or discrepancies in the borehole and assay data were identified and corrected. This included removing outliers or correcting missing values based on geological interpretation.

4.2 Geological Interpretation: Geological features such as faults, fractures, and mineralization patterns were incorporated into the database, ensuring that the 3D model reflected real-world geological conditions.

4.3 Data Formatting

The collected data were converted into CSV format for compatibility with SURPAC software. The tables were formatted to include:

1. Borehole coordinates (X, Y, Z)
2. Assay values (CaO, SiO_2, MgO, Fe_2O_3, etc.)
3. Lithological data (for geological modelling)
4. Survey data (for accurate borehole trajectory representation)
5. Geological Modelling in SURPAC

Once the data was validated and formatted, it was imported into SURPAC software for geological modelling. The modelling process included:

5. Block Modelling:

Using the validated borehole data, a block model was created to represent the spatial distribution of the limestone deposit. This model was used to estimate ore grades and calculate mineable reserves. Figure 2.2 & 2.3 shows the Block Model Space and Block Model of researched area.

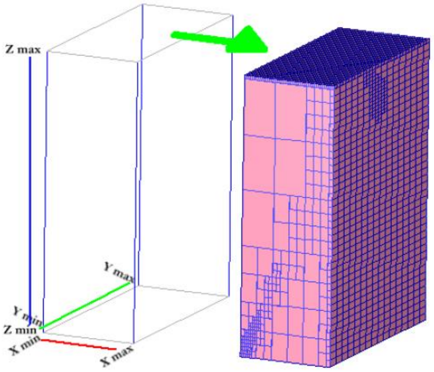

Fig. 2.2 Block Model Space

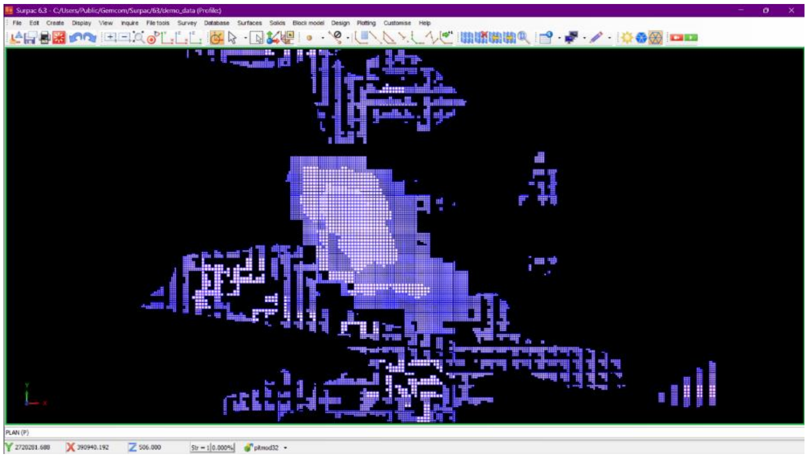

Fig. 2.3 Block Model

5.1 Stratigraphic Layers

Different lithological layers were delineated, including ore, inter-burden (IB), and overburden (OB), based on geological and assay data.

5.2 Grade Interpolation

The assay data were interpolated to estimate the average grade for each block in the model, allowing for the accurate definition of the ultimate pit limit.

5.3 Resource Estimation

The geological and assay data were used to estimate the total mineable reserves of the limestone deposit. The key steps included:

5.4 Resource Classification

Based on the grade and geological continuity, the resource was classified into measured, indicated, and inferred categories following standard industry practices.

5.5 Tonnes and Volume Calculation

Using the block model and grade interpolation results, the volume and tonnage of mineable limestone were calculated, which were critical for the economic evaluation of the mining project.

6. Data Integration and Optimization

The validated geological model was used as input for the UPL optimization in SURPAC. By integrating geotechnical, economic, and geological parameters, the software was used to determine the most profitable pit design, ensuring maximum recovery of limestone while adhering to safety and environmental constraints.

5. RESULTS AND DISCUSSION

The results of the Ultimate Pit Limit (UPL) optimization for the Daroli Limestone Mine, conducted using SURPAC software. The results highlight the outcomes of the optimization process, including the delineation of mineable reserves, the design of the ultimate pit, and the economic and operational implications of the optimized pit design. A comparison with traditional methods of pit design further emphasizes the advantages of using advanced mine planning tools.

1. Geological and Resource Estimation Results

The initial step in the optimization process involved the creation of a geological block model based on borehole data collected from the Daroli Limestone Mine. The model accurately represents the spatial distribution of limestone and waste rock across the deposit.

2. Mineable Reserves:

The total mineable reserves of limestone were estimated to be 132.289 million tons with an average grade of 46.3% CaO. This estimate was based on borehole assays, which were validated through laboratory analysis. The resource classification was as follows:

Proved Reserves: 132.289 million tons (High-grade limestone).

Probable Reserves: 9.252 million tons.

Feasibility Resources: 19.735 million tons (Blocked due to UPL benches and lease boundaries).

The estimated Lime Saturation Factor (LSF) for the limestone was calculated to be 139.92%, indicating that the limestone is of suitable quality for cement production.

Table 5.1 Shows the Detailed Reserve and Resource Estimation.

Resource Category	Quantity (Million Tons)	CaO (%)	SiO2 (%)	MgO (%)
Proved Reserves	132.289	46.3	8.53	< 4
Probable Reserves	9.252	46.3	8.53	< 4
Feasibility Resources	19.735	46.33	8.53	< 4

3. **Ultimate Pit Limit Optimization Results** The core of this study was the UPL optimization as shown in Figure 5.1, which was performed using SURPAC's Lerchs-Grossmann algorithm. The following key results were obtained:

3.1 Pit Boundary Design: The UPL optimization resulted in an economically viable pit boundary that maximizes the recovery of limestone while minimizing waste removal. The optimization process integrated factors such as ore grade, stripping ratio, market price of limestone, and geotechnical constraints (e.g., slope stability). The final optimized pit design resulted in a significant reduction of waste rock by focusing on high-grade ore zones. Design parameters are shown in Table 5.2.

Table 5.2 Design Parameters for Ultimate Pit Design

S. No.	Design Parameters	
1.	Bench Height	8.0 m
2.	Bench Width	20-30 m
3.	Haul Road Width	10 m
4.	Haul Road Gradient	1:16
5.	Slope of Bench	80°
6.	Ultimate Pit Slope Angle	32°-45°

3.2 Net Present Value (NPV): The optimization process led to an increase in the NPV of the project, as the design ensured the extraction of the most profitable blocks within the pit. The optimized UPL ensured that the most economically favourable areas of the deposit were mined first, leading to improved cash flow and profitability.

3.3 Pit Slope Design: The pit slopes were designed with angles ranging from 32° to 45°, based on geotechnical analysis. The slope stability was analysed to ensure safe mining operations, reducing the risk of slope failure and ensuring worker safety.

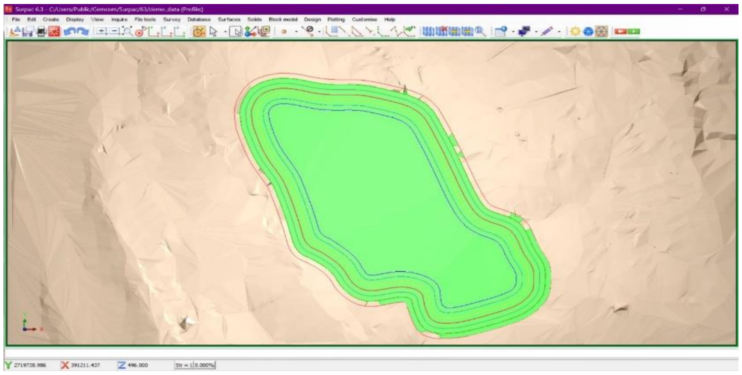

Figure 5.1 Ultimate Pit Design

4. **Comparison with Traditional Methods A comparison of the results from the software-based UPL optimization with those obtained using traditional methods highlights the advantages of using SURPAC:**

4.1 Traditional Methods: In traditional pit design, the UPL was calculated using basic cut-off grades and simple slope stability assessments. These methods were time-consuming and often resulted in suboptimal pit designs, where areas of high-grade limestone were overlooked in Favor of larger, more waste-heavy zones. Additionally, the manual methods were prone to human error and lacked the precision required for large-scale mining operations.

4.2 Software-Based Methods (SURPAC): The use of SURPAC software significantly improved the accuracy and efficiency of the UPL optimization process. The integration of geotechnical, economic, and geological data in real-time allowed for a much more precise pit design. SURPAC also enabled the quick assessment of multiple pit design scenarios, improving decision-making processes and ensuring the highest profitability.

Table 5.2 Provides a Comparative Summary of Key Metrics from Both Methods

Metric	Traditional Method	Software-Based Method (SURPAC)
Mineable Reserves	Less accurate estimate	132.289 million tons
Pit Slope Angle	Basic estimation (45° max)	32° to 45° based on geotechnical analysis
Production Efficiency	Lower due to waste handling	Optimized to minimize waste rock
NPV	Lower due to inefficient design	Increased through optimized pit design
Time to Complete Design	6 months or more	1 month

4.3 Economic and Operational Implication: The results of the UPL optimization have significant economic and operational implications:

1. Cost Reduction: By focusing on high-grade ore and minimizing waste removal, the optimized UPL design reduced operational costs, particularly in terms of excavation, haulage, and processing. The optimized pit slope design also reduced the need for additional support systems, further lowering capital expenditure.

2. Improved Safety: The geotechnical analysis ensured that the pit slopes adhered to safety standards, reducing the risk of slope failure and enhancing worker safety. The integration of real-time geotechnical data in SURPAC allowed for the design of stable slopes, which would have been challenging with traditional methods.

3. Sustainability: The optimized pit design helps minimize the environmental footprint of the mining operation by reducing the volume of overburden removed and the amount of waste generated. The efficient extraction process also reduces the environmental impact of waste disposal and minimizes the need for extensive reclamation efforts.

5. **Sensitivity Analysis and Model Validation:** A sensitivity analysis was conducted to assess how variations in key parameters (such as ore grade, market price, and slope angle) affected the final pit design. The results demonstrated that the SURPAC model was robust and capable of adapting to changes in market conditions and geological uncertainties. The model was further validated by comparing the results with field observations and historical mining data from the Daroli Limestone Mine. The consistency between the model's predictions and real-world data further supports the reliability of SURPAC software for UPL optimization. The final Ultimate Pit Limit Design shown in Figure 5.2.

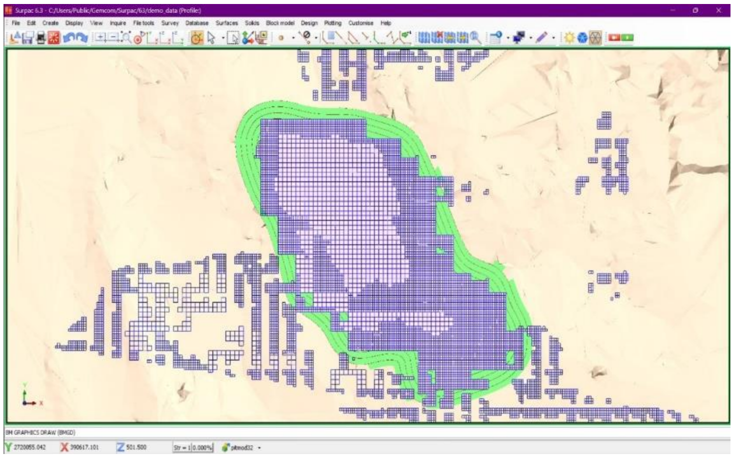

Figure 5.2 Ultimate Pit Limit Design Superimposed with Block Model

6. CONCLUSION

This study demonstrates the effectiveness of using **SURPAC software** for optimizing the **Ultimate Pit Limit (UPL)** in an opencast limestone mine. The integration of advanced computational tools into the mine planning process significantly improves the accuracy, efficiency, and economic viability of mining operations compared to traditional manual methods. The following conclusions can be drawn from this research:

1. **Enhanced Resource Utilization**: The optimized UPL design ensured maximum recovery of high-grade limestone while minimizing waste rock removal. A total of 132.289 million tons of mineable reserves were identified, with an average CaO content of 46.3%, confirming the economic viability of the deposit.

2. **Economic Benefits**: By incorporating geological, economic, and geotechnical data, the Lerchs-Grossmann algorithm in SURPAC maximized the Net Present Value (NPV) of the mining project. The optimized pit design reduced operational costs, improved production efficiency, and prioritized the extraction of the most profitable blocks.

3. **Improved Safety**: The geotechnical analysis conducted during the UPL optimization ensured that the pit slopes adhered to stability requirements, minimizing the risk of slope failures and enhancing worker safety. The pit slope angles, ranging from 32° to 45°, were optimized to maintain both safety and operational efficiency.

4. **Sustainability and Environmental Considerations**: The optimized pit design reduced overburden removal and waste generation, contributing to more sustainable mining practices. By focusing on high-grade zones and minimizing environmental disturbance, the project aligns with modern eco-friendly mining standards.

5. **Time and Cost Efficiency**: The use of SURPAC software reduced the time required for UPL optimization from months (using traditional methods) to just one month, while providing more accurate results. This efficiency translates into significant cost savings, making the mining operation more competitive.

6. **Comparison with Traditional Methods**: A comparison of traditional manual methods with SURPAC-based optimization highlighted the clear advantages of advanced mine planning tools. The software-based approach provided more precise reserve estimates, optimized slope designs, and better economic outcomes, demonstrating its superiority over conventional techniques.

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