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Study of Blast Fragmentation and Shovel Efficiency in a Surface Coal Mine

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Abstract: A significant proportion of mineral production is derived from surface mining operations, which have witnessed rapid growth due to the deployment of high-capacity equipment. The need to meet rising demand for minerals has led to the extensive use of heavy earth moving machinery (HEMM) such as shovels, excavators, and dumpers. These machines represent substantial capital investments, and their performance must be optimized for cost-effective mining. Among the many factors influencing equipment efficiency, the results of blasting—particularly the fragmentation size, distribution, and muck pile profile—play a critical role in determining the productivity of excavation and loading operations. Therefore, proper blast design is fundamental to the economic success of surface mining projects. Traditional methods such as trial-and-error and cratering are no longer viable for large-scale operations due to inefficiency and unpredictability. While empirical methods remain widely used for estimating blast design parameters, advancements in computer modeling offer promising alternatives that combine precision and adaptability. The integration of empirical formulas, simulation-based approaches, and instrumented field trials can significantly improve fragmentation outcomes. However, computational techniques are still underutilized in routine mine planning. This dissertation focuses on identifying both controllable and uncontrollable parameters that affect surface blast design. Using the well-known model by Langefors and Kihlstrom (1978) as a foundation, a computer model was developed—first in C++ and later migrated to a Java-based platform using NetBeans IDE 6.5. The software incorporates a database and user-friendly interface to aid in predicting fragmentation and optimizing blast design. The model was tested on both coal and iron ore mines, demonstrating reasonably accurate results. This study aims to bridge the gap between theoretical blast design models and practical field applications, ultimately enhancing the synergy between blast fragmentation and shovel efficiency in surface mining operations.

Keywords: Surface Mining, Blast Design, Fragmentation, Shovel Efficiency, Rock Blasting, Empirical Methods, Computer Modeling, Muck Profile, NetBeans, C++, Java Simulation.

I. INTRODUCTION

Mining, a practice that dates back to the Paleolithic era—approximately 30,000 years ago during the Stone Age—has long served as a cornerstone of human advancement and remains a fundamental pillar for the sustainable development of nations. Historical records indicate that some of the earliest organized mining activities were carried out by the Greeks as early as the sixth century B.C. Over the centuries, mining practices have evolved significantly and are generally classified into two major types: underground mining and surface mining. Underground mining has a rich and complex vocabulary developed over generations, as the techniques and tools used have become more sophisticated. One of the widely used techniques in underground mining is the room-and-pillar (also called board-and-pillar) method, where large chambers are excavated while leaving behind pillars of the ore or surrounding material to support the roof and maintain stability. Another significant approach is longwall mining, commonly utilized in coal extraction because of its productivity; this method involves the full extraction of coal seams using advanced shearer machinery, which leads to a managed settling of the layers above.Additionally, a variety of stoping methods are used for extracting metals from underground ore bodies, tailored to geological conditions and ore characteristics. On the other hand, surface mining has emerged as a more cost-effective and often safer alternative, especially for near-surface mineral deposits. It not only minimizes underground hazards but also enables larger-scale extraction, thereby contributing to higher production rates. As such, the choice between underground and surface mining is typically determined by factors such as depth of deposit, economic feasibility, safety considerations, and environmental impact. With the advancement of civilization and rapid industrialization, the demand for various minerals has increased substantially, compelling the establishment of large-scale surface mines with production targets reaching millions of tons annually. The fundamental objective of any mining operation is to ensure the maximum extraction of minerals in a manner that is economically profitable, environmentally responsible, and safe for workers and surrounding communities.

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In the last thirty years, the mining industry has witnessed remarkable expansion, largely fueled by the introduction of high-capacity machinery and cutting-edge technologies. The adoption of advanced earthmoving equipment, continuous mining systems, improved explosives, modern blasting accessories, and innovative processing techniques, along with the increasing use of information and computational tools, has significantly boosted production levels. However, these advancements require substantial capital investment, necessitating careful planning and optimization by mining engineers to maximize the performance of costly equipment. The efficiency of excavation and material handling machinery is heavily dependent on the effectiveness of blasting, particularly regarding the size, distribution, and profile of the fragmented rock. Consequently, well-designed blasting operations play a vital role in ensuring cost-effective mining. Although continuous rock-cutting technologies have emerged, drilling and blasting remain the predominant rock breakage methods due to their versatility, adaptability, and economic advantages in diverse geological and mining conditions. N To reduce the overall production costs in surface mining, achieving optimal rock fragmentation through a well-planned blasting design is crucial. The size and distribution of the blasted rock fragments significantly influence the efficiency of subsequent processes such as loading, hauling, and crushing. Poor fragmentation that produces oversized boulders slows down excavation and transportation operations and requires additional tasks like sorting, secondary blasting, and breaking, thereby increasing both operational expenses and cycle times. Conversely, generating excessive fines during blasting is also problematic, as it suggests an overuse of explosives, leading to resource wastage and potential environmental harm. Therefore, the objective is to obtain a consistent and controlled fragmentation profile that minimizes both oversized material and fine particles, ensuring smooth and cost-efficient operations. Typically, surface mines rely on trial blasts to determine suitable blast patterns; however, these empirically derived designs often fail to produce consistent outcomes due to variations in geological and geotechnical conditions. This variability underscores the need for a more systematic and dependable approach. Developing a software-based solution for surface blast design, utilizing the framework proposed by Langefors and Kihlstrom (1978), would enable improved prediction, design accuracy, and control over blasting results. Such a tool would enhance operational performance, lower costs, and contribute to safer mining practices.

II. SURFACE BLAST DESIGN

A. OVERVIEW

Due to the inherent variability in rock properties across different sites, the most reliable approach remains iterative field experimentation and adjustment. While it is impractical to predict every site-specific condition in advance, this chapter intends to establish a foundational understanding for preliminary geometric design, charge calculation, and rock classification based on uniaxial compressive strength. Ultimately, on-site adjustments to blast patterns and charge configurations are essential to accommodate variations in geology, ensuring optimal performance, safety, and economic efficiency in blasting operations.

B. SMALL DIAMETER BENCH BLAST

As discussed earlier, small-diameter bench blasting generally uses blasthole diameters between 65 mm (2.56 inches) and 165 mm (6.50 inches). This blasting technique is primarily employed in small-scale surface mining, construction excavations, and quarrying operations where controlled fragmentation, precision, and minimal environmental disturbance are essential. Although these operations are smaller in scale, the design and implementation of small-diameter blasts demand careful planning because numerous interdependent factors influence both performance and safety.nDuring the preparation stage, critical parameters such as the chosen drill diameter, bench height, sub-drilling depth and pattern, as well as stemming length and material, must be carefully considered to ensure effective confinement of explosive energy. Additionally, the angle or inclination of the blasthole significantly affects energy distribution and controls the resulting breakage pattern. The method of charge distribution within the hole is equally crucial, as it determines how efficiently explosive energy is transmitted through the rock mass to achieve the desired fragmentation while minimizing risks such as fly rock, excessive breakage, or unwanted vibrations.nThe complex interaction of these factors requires a site-specific approach that is often fine-tuned through field observations and empirical adjustments, enabling the attainment of optimal results in small-diameter bench blasting applications.

1) *Drill Diameters:* Drill Diameters play a significant role in the overall design and cost-effectiveness of bench blasting operations. When selecting the appropriate blasthole diameter, several key factors must be carefully evaluated, including the average production rate per hour and the type of material to be excavated. These considerations help in matching the drilling effort to the required output and rock characteristics, ensuring both technical and economic efficiency.

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In general, larger diameter blastholes are preferred in high-production environments, as they accommodate greater explosive charges and enable larger volumes of rock to be broken per blast, thereby improving productivity. However, for smaller-scale operations or where precise control over fragmentation is needed, smaller diameters may be more appropriate.
Another critical factor influencing the choice of drill diameter is the drilling cost, which is directly related to equipment type, operating time, and fuel consumption. Interestingly, as the blasthole diameter increases, the cost per unit volume of rock excavated tends to decrease, primarily due to the higher efficiency and reduced number of holes needed to break the same volume of rock. This cost advantage makes large diameter drilling economically attractive, especially in large surface mines and quarries. However, larger diameter drills also require more capital investment and may not be suitable for all terrains or formations. Therefore, the final selection of drill diameter must strike a balance between the desired production capacity, material characteristics, fragmentation requirements, and economic feasibility to ensure optimal performance in blasting operations.

Table 5.1: Effect of Drill Hole Diameter on Average Production

Blast Hole Diameter (mm)	Average Production per Hour (m^3/h) – Medium-Soft Rock (< 120 MPa)	Average Production per Hour (m^3/h) – Hard to Very Hard Rock (> 120 MPa)
65	190	60
89	250	110
150	550	270

2) *Bench Height*: Bench Height is a critical parameter in bench blasting design, as it directly influences drilling efficiency, blast performance, and compatibility with loading equipment. When determining the appropriate bench height, two primary factors must be considered: the diameter of the blasthole and the type of loading equipment that will be used during excavation. Generally, there is a proportional relationship between blasthole diameter and bench height—larger diameter holes are suitable for higher benches due to their ability to accommodate longer explosive charges and deeper drilling depths. The selection of bench height must also align with the reach and bucket capacity of the loading equipment (such as shovels, excavators, or loaders) to ensure smooth and efficient material handling post-blast. If the bench is too high relative to the equipment's capacity, it may lead to operational delays, safety concerns, or the need for secondary breakage. Conversely, excessively low benches can lead to increased drilling and blasting costs per unit volume and may reduce overall productivity.

Table 5.2: Correlation Among Bench Height, Borehole Diameter, and Loading Equipment Selection

Bench Height H (m)	Blasthole Diameter D (mm)	Recommended Loading Equipment
8.0 – 10.0	65 – 90	Front End Loader
10.0 – 15.0	100 – 150	Hydraulic or Rope Shovel

3) *Burden (B)andSpacing (S):* Burden (B) and Spacing (S) are two of the most fundamental geometric parameters in bench blasting design, directly influencing fragmentation quality, explosive efficiency, and blast safety. The burden refers to the shortest distance from the center of a blasthole to the nearest free face, and it controls the direction in which the rock will move upon detonation. The spacing, on the other hand, is defined as the distance between adjacent blastholes in the same row and determines the lateral confinement of the charge. The correct combination of burden and spacing ensures that the rock mass breaks effectively and is displaced in a controlled manner, minimizing issues such as flyrock, backbreak, or underbreak. The selection of appropriate burden and spacing values is dependent on several interrelated factors. These include the drilling diameter, mechanical properties of the rock (such as its compressive and tensile strength), explosive characteristics (such as density and detonation pressure), bench height, and the desired degree of fragmentation and displacement. Each of these factors influences how the explosive energy is distributed and absorbed within the rock mass.

Table 5.3: Effect of Rock UCS and Borehole Diameter on Blast Design Parameters

Design Parameter	Low (UCS < 70 MPa)	Medium (70–120 MPa)	High (120–180 MPa)	Very High (> 180 MPa)
Burden (B)	39 × D	37 × D	35 × D	33 × D
Spacing (S)	51 × D	47 × D	43 × D	38 × D
Stemming (T)	35 × D	34 × D	32 × D	30 × D
Sub-Drilling (J)	10 × D	11 × D	12 × D	12 × D

4) *. Stemming (T):* Stemming (T) is a critical component in the bench blasting process, serving the essential purpose of confining the explosive gases within the borehole. This confinement ensures that the energy generated from the detonation is effectively transmitted into the surrounding rock mass, promoting efficient fragmentation and minimizing the escape of gases through the collar of the hole. Accurate calculation and execution of stemming are just as vital as burden and spacing, as errors in stemming design can significantly degrade blast performance and safety.
5) *Sub Drilling (J):* Sub Drilling (J) refers to the additional depth drilled below the planned floor level of a bench blast. Its purpose is to ensure complete shearing and breakage of the rock at the base of the bench, eliminating the formation of an unblasted "toe" that can obstruct excavation and reduce loading efficiency. While sub drilling is not included in the calculation of the total blasted volume, it plays a vital role in improving fragmentation at the floor level, enabling efficient mucking and reducing the need for secondary blasting or mechanical removal. If sub drilling is insufficient, the explosives fail to completely fracture the rock at the base, leaving behind a toe—a solid ridge of unbroken material at the bench floor. This not only requires additional time and energy for removal but also increases the cost of loading and hauling, reduces productivity, and can create uneven floor levels that hinder the movement and stability of loading equipment. Conversely, excessive sub drilling introduces a different set of problems. Drilling deeper than necessary increases both drilling and explosive consumption, directly raising operational costs. It also causes unnecessary overbreak, which can result in excessive fragmentation, instability in the bench toe or slope face, and a higher risk of vibration-related issues, such as cut-offs (where explosives fail to detonate properly) and damage to final pit walls or haul roads in the blast perimeter.
6) *Inclination of the Blasthole (β):* Inclination of the Blasthole (β) is an important design consideration in bench blasting that significantly affects fragmentation quality, drilling efficiency, and overall blasting performance. While vertical drilling is commonly used for its simplicity and ease of execution, research and practical field applications have shown that inclined drilling—also referred to as angled or slant drilling—offers numerous advantages with only a few manageable disadvantages. Among the key benefits of inclined blastholes is the achievement of better fragmentation, particularly near the toe and collar zones, where vertical holes often leave oversized blocks. Inclined holes are more effective in distributing explosive energy across the rock mass, facilitating uniform breakage and minimizing the formation of unbroken toes. Another advantage is a reduction in the required sub drilling length, as inclined holes naturally direct the explosive energy beneath the floor level, enhancing bottom breakage without excessive depth. This not only reduces the drilling cost per blast but also lowers the powder factor, making the blast more economical. Additionally, inclined drilling often leads to improved drilling productivity because it allows for better alignment with natural rock discontinuities, reducing resistance and wear during the drilling process. However, there are some trade-offs associated with inclined drilling. One of the main challenges is the increased length of the blasthole, which results from the slanted trajectory required to reach the desired collar and floor positions. Longer holes mean more drilling time and greater wear and tear on drill bits, especially in hard or abrasive rock conditions. Charging inclined holes with explosives can also be slightly more complex, as gravity affects the uniform distribution of explosive materials, especially when using granular or powdered explosives. Despite these challenges, the overall advantages of inclined drilling often outweigh the disadvantages, particularly in situations where precise control over fragmentation and reduced toe formation are critical. With proper equipment, skilled operators, and carefully selected drilling angles (typically ranging from 10° to 30°), inclined blastholes can significantly enhance blasting outcomes and operational efficiency in surface mining and construction projects.
7) *Charge Distribution:* Charge Distribution in bench blasting plays a critical role in achieving efficient and controlled rock fragmentation. Since the energy required to break rock is not uniform throughout the bench, proper distribution of explosive energy within the blasthole is essential for overcoming different rock failure mechanisms—namely tensile and shear strengths. The tensile failure zone typically occurs near the free face (denoted as section CDD'C'), while the shear failure zone is found deeper within the rock mass (section A'B'C'D'). To address these varying requirements, the charge is strategically divided into two distinct sections: the bottom charge and the column charge. The bottom charge, located at the base of the blasthole, consists of a high-density, high-energy explosive designed to concentrate energy at the toe of the bench, where rock is most resistant to breakage. This charge ensures deep penetration of explosive energy and effectively initiates the required shear and tensile failure. Research and practice indicate that the energy concentration in the bottom charge should be 2 to 2.5 times greater than the average energy required for rock breakage, thereby guaranteeing sufficient force to initiate crack propagation from the bottom upward. It is also observed that placing high-strength explosives at the bottom tends to increase the effective diameter of shaped charges by approximately 10%, enhancing the blasting impact in the confined bottom region. Above the bottom charge lies the column charge, which occupies the remaining part of the blasthole above the stemming.

This section uses an explosive of lower density and strength since the rock near the upper part of the bench is relatively easier to break due to its proximity to the free face. The height of the column charge is determined by subtracting the lengths of the bottom charge and stemming from the total depth of the blast hole.

Table 5.4: Effect of Rock UCS and Borehole Diameter on Bottom Charge Length

Design Parameter	Soft (UCS < 70 MPa)	Medium (70–120 MPa)	Hard (120–180 MPa)	Very Hard (> 180 MPa)
Bottom Charge Length	30 × D	35 × D	40 × D	46 × D

8) *Powder Factor:* Powder Factor is a crucial parameter in blasting operations that reflects the relationship between the amount of explosive used and the volume of rock excavated. It is often referred to as the specific charge and is expressed as the quantity of rock broken (in cubic meters) per kilogram of explosive consumed. Mathematically, it is the inverse of explosive consumption per unit volume and serves as a practical measure for evaluating the efficiency and economy of a blast.

$$\text{Powder Factor} = \text{Volume of rock excavated } (m^3) / \text{ Weight of explosive used (kg)}$$

A higher powder factor indicates greater efficiency, as more rock is fragmented with less explosive, whereas a lower powder factor suggests higher explosive consumption, which may or may not be ideal depending on rock type and desired fragmentation.

The powder factor varies based on the geological conditions, rock hardness, desired degree of fragmentation, and the type of explosives used. For example, in soft or moderately hard rock formations, less energy is needed to achieve breakage, so the powder factor will be higher. In contrast, in harder rock types, more energy is required, and hence, the powder factor will be lower. As per the rock groups categorized in Table 7, the powder factor generally ranges from 0.25 to 0.55 kg/m³. Lower values (around 0.25 kg/m³) are typical for hard, dense rocks requiring more energy to fracture, whereas higher values (closer to 0.55 kg/m³) apply to softer, more friable rocks that break more easily. Selecting the optimal powder factor is essential not only for achieving effective fragmentation but also for minimizing costs, vibration, flyrock, and environmental impact. Proper control of this parameter, combined with accurate burden, spacing, and charge distribution, ensures a successful and efficient blasting operation.

C. LARGE DIAMETER BENCH BLASTING

Large-diameter bench blasts, generally utilizing blasthole diameters between 165 mm and 450 mm, are primarily used in large-scale surface mining and specific civil engineering applications, including quarrying for dam construction, site preparation for power plants, and mass excavation works. These blasts are engineered to fragment large rock volumes in a single detonation, making them particularly effective for operations that demand significant material displacement and high production efficiency.

1) *Drilling Diameters:* Drilling Diameters in large diameter bench blasting follow many of the same design principles as those used in small diameter blasting; however, the scale and impact of drilling decisions are significantly magnified due to the larger volumes of rock involved and the greater energy release. When determining the suitable drill diameter for large-diameter blasting, typically ranging from 165 mm to 450 mm, several key factors must be considered, including the targeted hourly production rate, the type and hardness of the rock, and the overall excavation objectives. As with small-diameter blasting, rock properties—whether soft, medium-hard, or hard—play a crucial role in dictating the energy needed for effective fragmentation and, in turn, the drill diameter required to hold an adequate explosive charge.

Other factors, such as the targeted fragmentation size, the capacity of loading equipment, and permissible vibration levels, also affect the selection of drilling parameters. A major benefit of using larger diameter holes is their ability to hold greater explosive quantities per hole, which allows larger rock volumes to be fragmented in a single blast. This enhances productivity and reduces the total number of holes required, ultimately lowering the drilling cost per cubic meter of rock despite the higher cost of drilling each large-diameter hole. Additionally, these holes facilitate the use of bulk explosives, further improving cost efficiency and overall blast performance.

However, the use of larger diameters demands higher precision in drilling alignment, inclination, and the burden-to-spacing ratio to maintain proper fragmentation and prevent issues such as overbreak, toe formation, or excessive flyrock. Therefore, while the basic criteria for selecting drill diameters in large-diameter bench blasting—mainly rock properties and production requirements—remain unchanged, the potential impact of design inaccuracies is considerably greater, necessitating careful planning and accurate execution to achieve the desired outcomes (as detailed in Table 5.5).

Table 5.5: Effect of Blasthole Diameter and Rock Type on Average Production

Blasthole Diameter (D) [mm]	Average Production per Hour (m³/h) – Soft Rock (< 70 MPa)	Medium to Hard Rock (70–180 MPa)	Very Hard Rock (> 180 MPa)
200	600	150	50
250	1200	300	125
311	2050	625	270

2) *Bench Height:* Bench Height in large diameter bench blasting is a crucial parameter that directly influences blast performance, loading efficiency, and operational productivity. In large-scale surface mining and heavy civil engineering applications, determining the optimal bench height ensures that the rock is fragmented effectively and that the broken material can be loaded safely and efficiently by heavy machinery, such as rope shovels or large excavators.

There are two primary methods used to calculate the bench height for large diameter blastholes:

1) *Equipment-Based Approach***:** This method considers the capacity and reach of the loading equipment, particularly rope shovels. The bench height (H) is estimated using the following empirical formula:

$$H=10+0.57(Cc-6)$$

Where:

- H = bench height (in meters)
- Cc = bucket capacity of the rope shovel (in m^3)

This equation ensures that the bench height is compatible with the shovel's digging capabilities, allowing efficient material handling without re-positioning the machine or creating difficult loading conditions. For example, a shovel with a 12 m^3 bucket would result in a bench height of:

$$H=10+0.57(12-6)=10+3.42=13.42 \text{ meters}$$

2) *Rock Strength-Based Approach:* Another method to determine bench height is based on the uniaxial compressive strength (UCS) of the rock in combination with the blasthole diameter. Stronger rocks typically require greater energy to fracture, which may necessitate taller benches to accommodate sufficient charge length and explosive distribution. This method relies on empirical relationships and design charts such as those provided in Table 9, which correlate compressive strength categories (soft, medium, hard) with suitable bench heights and blasthole diameters.

Table 5.6: Correlation Between Bench Height, Stemming Length, Borehole Diameter, and Rock UCS

Design Parameter	Low (UCS < 70 MPa)	Medium-High (70–180 MPa)	Very High (> 180 MPa)
Bench Height (H)	52 × D	44 × D	37 × D
Stemming (T)	40 × D	32 × D	25 × D

3) *Stemming:* Stemming in large diameter bench blasting serves the essential function of confined detonation energy, preventing premature escape of gases and directing the energy into effective rock fragmentation. The proper length of stemming is critical—it ensures the explosive force is fully utilized while minimizing adverse effects such as flyrock, air blast, and noise. To calculate appropriate stemming length for large diameter holes, engineers refer to empirical relationships that factor in two key parameters:

- Diameter of the blasthole (D)
- Uniaxial Compressive Strength (UCS) of the rock

4) *Sub Drilling:* Sub Drilling is the additional depth drilled below the planned bench floor to ensure complete breakage at the base of the blast. It is essential for eliminating the formation of toe—the unbroken rock ridge that remains after blasting—thereby improving mucking efficiency and ensuring a clean and level bench floor for the next mining or excavation cycle. In large diameter bench blasting, sub drilling is typically expressed as a multiple of the blasthole diameter (D), and its value is determined based on rock strength, bench design, and desired floor conditions. Table 10 provides standard sub drilling values for different blasthole diameters and rock types.

5) *Sub Drilling:* Sub Drilling is the additional depth drilled below the intended bench floor to ensure complete fragmentation of rock at the base and avoid the formation of a toe—a ridge of unblasted or poorly fragmented material that hinders excavation and reduces overall productivity. In large diameter bench blasting, sub drilling is not included in the blast volume calculation but is essential for achieving effective floor breakage and operational continuity.

Sub drilling is commonly determined using empirical relationships, most often as a proportional multiple of the blasthole diameter (D). This approach simplifies field implementation and provides consistency across different blasting scenarios.

As per Table 5.6, general guidelines for sub drilling are:

Rock Type	Sub Drilling (as a multiple of D)
Soft rock	0.2 × D
Medium rock	0.25 × D
Hard rock	0.3 × D

6) *Inclination:* Inclination in large diameter bench blasting is typically avoided due to the practical challenges involved in drilling large-diameter holes at an angle. As the diameter of the blasthole increases, maintaining alignment, stability, and equipment control becomes increasingly difficult, especially in hard rock conditions. As a result, most large-diameter blastholes are drilled vertically, ensuring operational simplicity, safety, and accuracy. However, there are notable exceptions where inclined drilling is not only feasible but also beneficial. Specifically, in soft rock formations and in benches with heights exceeding 24 meters, inclined blastholes can offer significant advantages. Inclined drilling in such cases helps:

- Achieve better fragmentation, especially near the toe zone,
- Reduce the amount of sub drilling required,
- Improve muck pile throw and diggability, and
- Provide better alignment with natural rock discontinuities for enhanced breakage.

7) *Drill Patterns:* Drill Patterns are a fundamental aspect of blast design in large diameter bench blasting. The arrangement and spacing of blastholes significantly influence the fragmentation quality, vibration control, muck pile profile, and overall blast efficiency.

As discussed earlier, the burden (B)—the distance between the blast hole and the free face—is directly affected by three main variables:

- The charge (hole) diameter (D)
- The uniaxial compressive strength (UCS) of the rock
- The specific energy or strength of the explosive being used

Generally, as the diameter of the blast hole increases, a greater burden can be used due to the increased explosive energy. Similarly, stronger rocks or weaker explosives will require a smaller burden to ensure effective breakage.

The column charge, which occupies the portion of the blasthole above the bottom charge and below the stemming, typically uses the same diameter as the drilling diameter unless specialized cartridges or liners are used.

Drill Pattern Design:

The most commonly used drill patterns in large diameter blasting include:

- Square Pattern: Equal spacing between rows and columns; used for uniform breakage and when throw is not a major concern.
- Rectangular Pattern: More spacing in one direction; allows better control of muckpile shape and is used for specific excavation directions.
- Staggered (Triangular) Pattern: More effective energy distribution; improves fragmentation and is useful when dealing with irregular faces or variable rock conditions.

Table 5.7: Optimized Burden and Spacing Parameters for Different Rock Compressive Strengths and Explosives

Type of Explosive	Design Parameter	Soft Rock (UCS < 70 MPa)	Medium-Hard Rock (70–180 MPa)	Very Hard Rock (> 180 MPa)
ANFO	Burden (B)	28 × D	23 × D	21 × D
	Spacing (S)	33 × D	27 × D	24 × D
Water Gels / Emulsions	Burden (B)	38 × D	32 × D	30 × D
	Spacing (S)	45 × D	37 × D	34 × D

8) *Charge Distribution:* Charge Distribution in large diameter bench blasting is a critical aspect of blast design that directly impacts fragmentation quality, cost-efficiency, blast safety, and overall mine productivity. In large surface operations, the selection and arrangement of explosive materials within the blasthole must be carefully optimized to achieve these objectives. A widely used explosive in such operations is ANFO (Ammonium Nitrate Fuel Oil), primarily because of its distinct advantages:

- Low cost makes it economically viable for large-scale operations.
- High bubble energy ensures efficient rock fragmentation.
- Safe handling and storage characteristics make it reliable in the field.
- Ease of mechanization, especially with bulk loading systems, enhances operational efficiency.

However, ANFO is not water-resistant, which limits its use in wet blastholes or groundwater-prone zones. In such cases, alternative explosives like water gels or emulsions are used. These are particularly effective when:

- The lower portion of the blasthole is waterlogged.
- A primer or booster charge is required to initiate the column charge.

The standard practice in modern large diameter blasting is to use a composite charging system:

- A high-density explosive such as a water gel or emulsion forms the bottom charge, typically extending 8 to 16 times the blasthole diameter (D). The exact length is selected based on rock hardness and desired energy concentration.
- The remaining column is filled with ANFO, which provides sufficient energy for rock mass displacement and fragmentation at an economical cost.

D. COMPUTATIONAL APPROACH

A blast design software, developed on the principles proposed by Langefors and Kihlstrom, has been created to support engineers in designing and analyzing surface blasting operations. This approach utilizes empirical formulas, derived from both field experience and scientific principles, to determine key blasting parameters such as burden, spacing, sub-drilling, stemming, and charge distribution. Initially programmed in C++, the software was later enhanced using the NetBeans IDE to deliver a more stable and user-friendly interface. It features a structured design logic flow, depicted in Figures H1 to H6, which systematically guides users from data input to the generation of results.

1) Flow Sheet

The surface blast design methodology, as proposed by Langefors and Kihlstrom, serves as the foundational framework for the development of this software system. This method offers a systematic and analytical approach to blasting operations in surface mining, particularly in hard rock excavation, and is widely regarded for its precision and reliability. The methodology has been translated into a comprehensive flow sheet, which visually illustrates the sequence of operations involved in blast design. This flow sheet is structured to depict both logical and mathematical calculations in a step-by-step manner, thereby ensuring a clear understanding of each phase of the design process. Initially, the methodology begins with the collection of site-specific data, including rock mass properties, bench dimensions, and the desired fragmentation level. This is followed by the calculation of burden and spacing, which are critical parameters governing the effectiveness of explosive energy distribution. Subsequently, the design process incorporates the determination of drilling patterns, explosive charge per hole, and stemming length, ensuring that the blast energy is optimally confined and directed. Further stages involve evaluating the powder factor, charge concentration, and delay timing sequence, all of which significantly influence fragmentation outcomes and minimize ground vibration.

The final stages include a simulation or estimation of blast results, where the blast performance is assessed based on predicted throw, fragmentation, and muckpile shape. Each component of this methodology is logically interlinked and mathematically supported, facilitating the development of an efficient and site-adaptable surface blasting design. The software embeds this flow sheet as its algorithmic core, allowing users to input relevant parameters and receive optimized blast designs that conform to the principles established by Langefors and Kihlstrom.

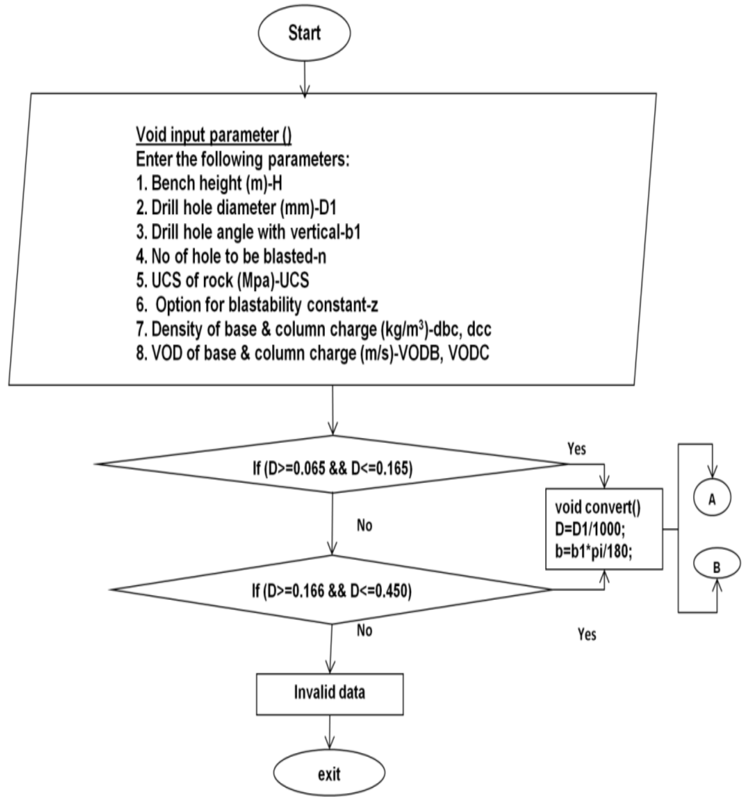

Fig.5.1: H1 – Initial Design Inputs

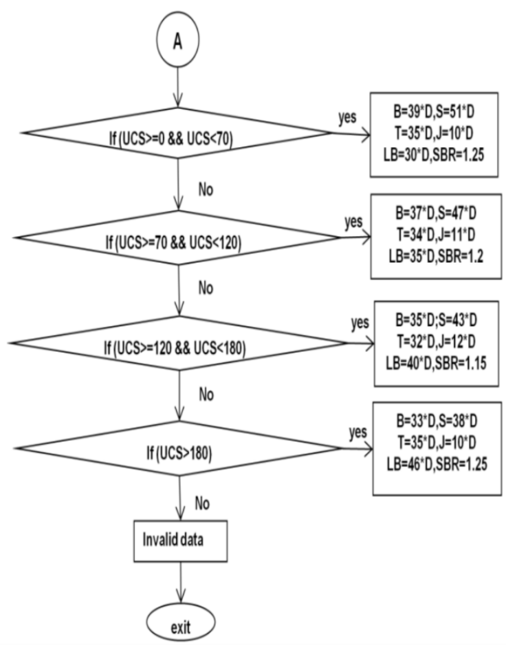

Fig.5.2: H2 – Design Parameters for Small-Diameter Blast Holes

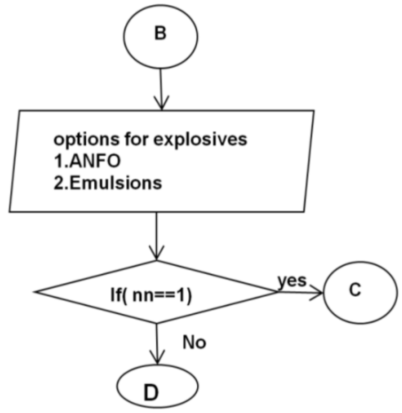

Fig.5.3: H3 – Explosive Selection Criteria

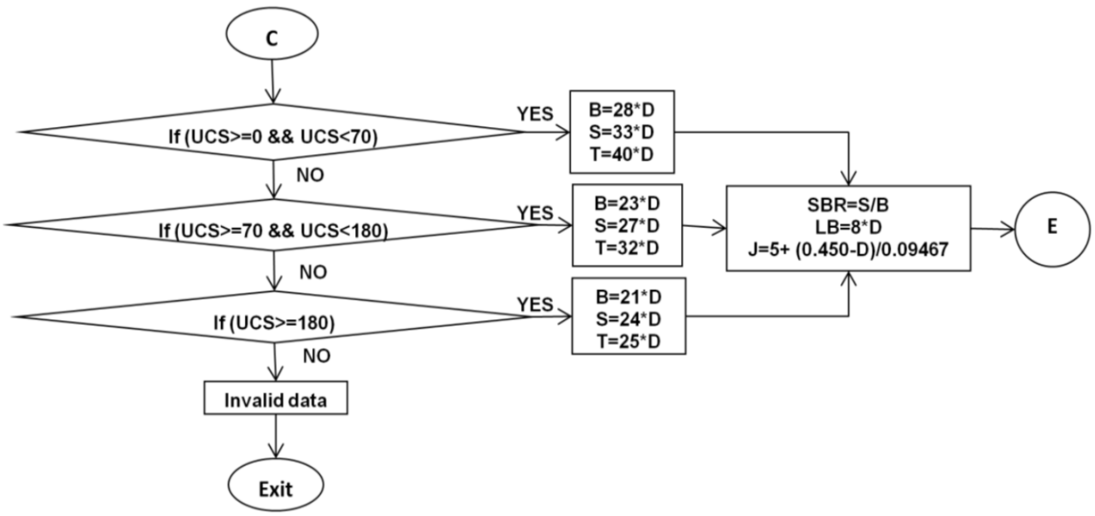

Fig.5.4: H4 – Design Parameters for Large-Diameter Blast Holes Using ANFO

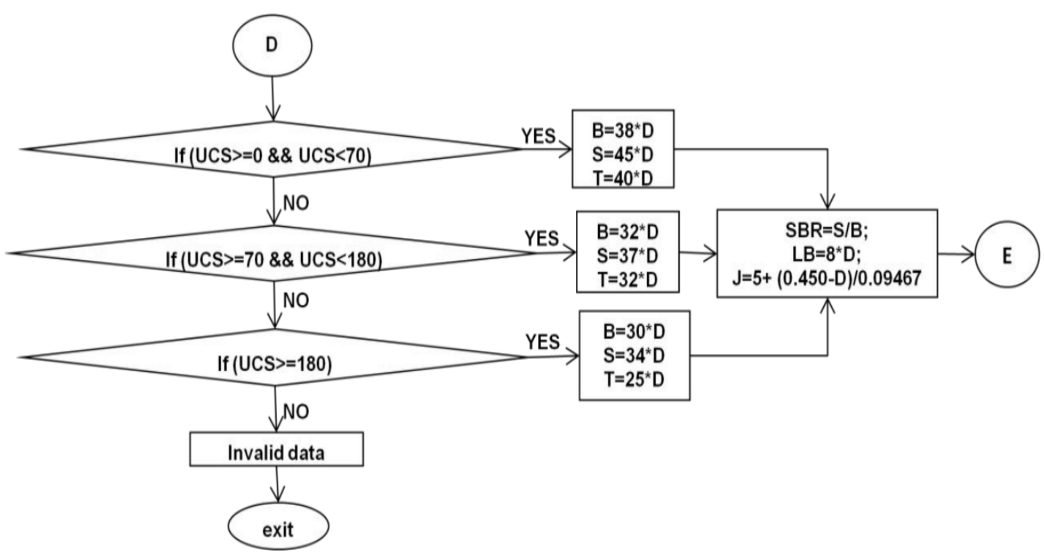

Fig.5.5: H5 – Optimized Parameters for Emulsion Use in Large-Diameter Blastholes

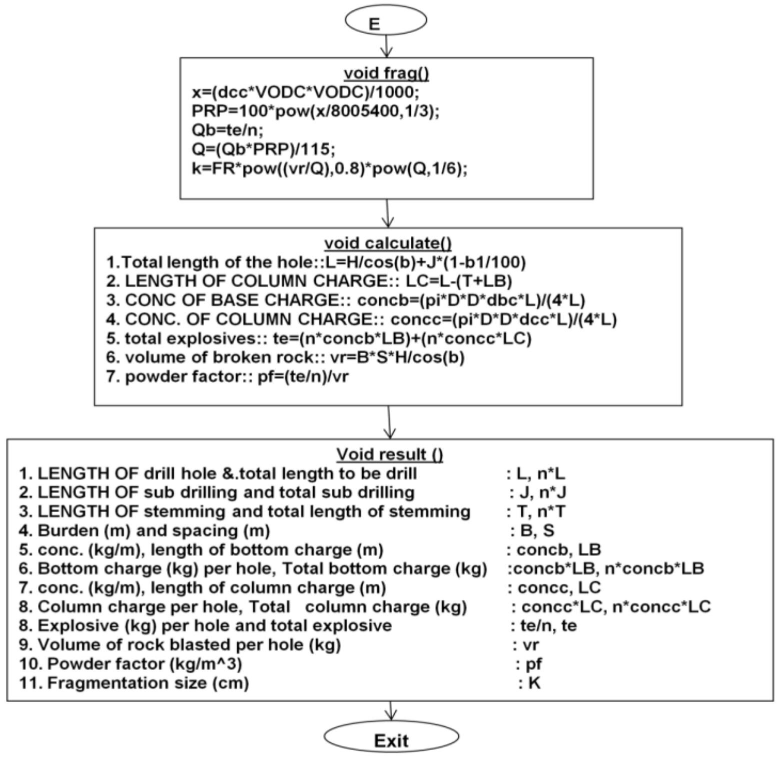

Fig.5.6: H6: Analysis and Derived Results

2) The software (OCBLASTS 1.0)

a) Designed model in C++

The OCBLASTS 1.0 software module was developed during the previous academic semester using the C++ programming language. This language was chosen due to its robustness, speed, and compatibility with low-level hardware interactions, which are essential for developing engineering software with high computational requirements. The designed model offers a user-friendly interface that facilitates both screen-based input and output operations. It is capable of accepting real-time user inputs related to surface blast design parameters such as burden, spacing, bench height, hole diameter, specific charge, stemming, and powder factor. The outputs, which include calculated values and derived blast patterns, are displayed interactively on the screen for immediate user feedback and validation. Additionally, the model includes a feature that enables data persistence through file handling mechanisms. Based on the user's command, the program can store both input data and the corresponding output results in structured text files. This functionality is particularly useful for documentation, result verification, future reference, and batch processing of multiple blasting scenarios. The file-handling operations are efficiently managed using standard C++ file streams (ifstream and ofstream), ensuring that the data is written and retrieved in an organized and error-free manner. Overall, the C++-based implementation of OCBLASTS 1.0 represents the core computational engine of the software, incorporating the step-by-step logic of surface blast design as per the Langefors and Kihlstrom methodology. It serves as the fundamental building block upon which further enhancements, such as GUI development or integration with database systems, can be implemented in future versions.

- Screen Input Functionality:

The screen input functionality in the OCBLASTS 1.0 software allows users to input the required blasting parameters interactively, one at a time, through a simple and intuitive console-based interface. Each parameter—such as burden, spacing, bench height, hole diameter, stemming length, and explosive properties—is prompted sequentially, ensuring that the user can carefully enter and verify each value. To enhance usability and minimize errors, the system includes a reload feature. In the event of incorrect data entry or the need to revise previously entered parameters, the user can restart the input process at any time by pressing the "R" or "r" key. Upon pressing this key, the program will return to the initial input screen, allowing the user to re-enter all parameters from the beginning without needing to exit or terminate the program manually. This feature ensures flexibility and user control, significantly reducing the chances of proceeding with inaccurate data and improving the overall reliability of the software.

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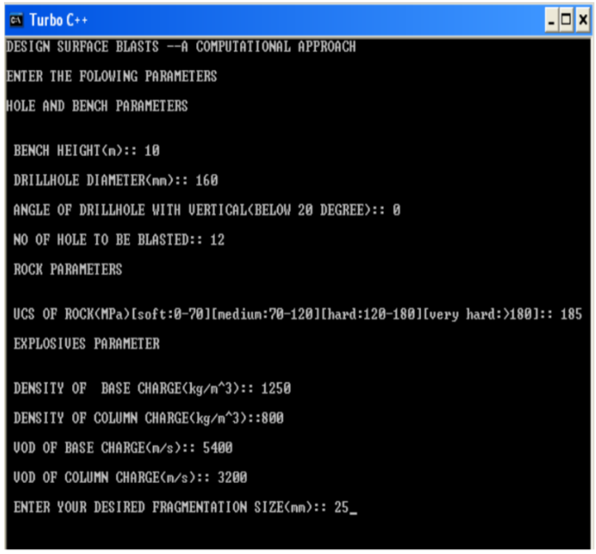
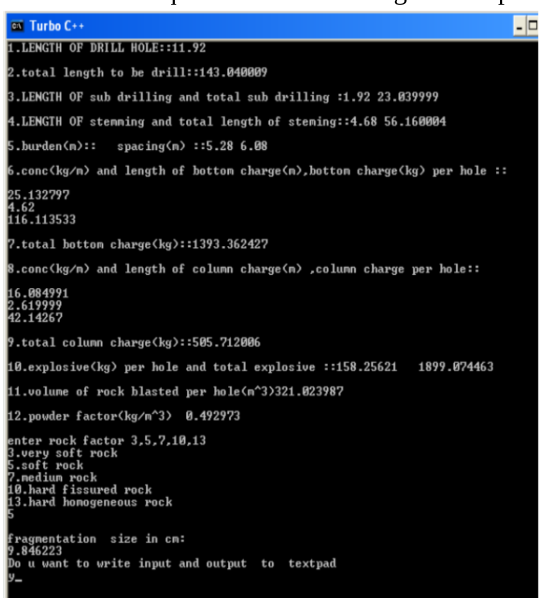
This approach not only provides a clear and organized method for data entry but also aligns with good programming practices in terms of user interaction, input validation, and error recovery in a command-line environment.



- Screen Output Functionality:

The screen output module of the OCBLASTS 1.0 software is designed to display the computed results of the surface blast design parameters directly on the console interface in a structured and readable format. After the user inputs all the required data, the program performs the necessary calculations based on the Langefors and Kihlstrom methodology and generates the output instantly for review.The software displays all these values in an organized manner, making it easy for users to interpret and evaluate the design. This real-time display feature is especially useful for educational, experimental, and field-testing purposes, as it allows immediate validation of input parameters and facilitates quick decision-making in blast planning.



b) Design model In Net Beans

To enhance user-friendliness, the OCBLASTS 1.0 software has been further developed using the Java programming language, leveraging the NetBeans 6.0 Integrated Development Environment (IDE). The decision to migrate to the Java platform from the earlier C++ implementation was motivated by the need for improved graphical user interface (GUI) capabilities, enhanced platform independence, and better modular integration features.

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The NetBeans Platform provides a powerful and reusable framework that simplifies the development of complex desktop applications. It enables developers to build modular applications that are easy to maintain, extend, and update. When a NetBeans-based application is launched, the platform's core Main class is executed, which then identifies and loads available application modules. These modules are stored in an in-memory registry, and their startup tasks are executed accordingly. One of the key features of the platform is on-demand loading, where module code is only loaded into memory when required, thereby optimizing system resource usage.

One of the key benefits of utilizing the NetBeans Platform is its capability to support dynamic module installation and updates. Applications built on this platform can incorporate the Update Center module, enabling users to directly download and install digitally signed updates and new features into the running application. This functionality removes the need for full software reinstallation during upgrades, ensuring a smooth and efficient update process. The NetBeans Platform also offers a wide array of built-in features that benefit the development and functionality of engineering software like OCBLASTS 1.0. Notable features include:

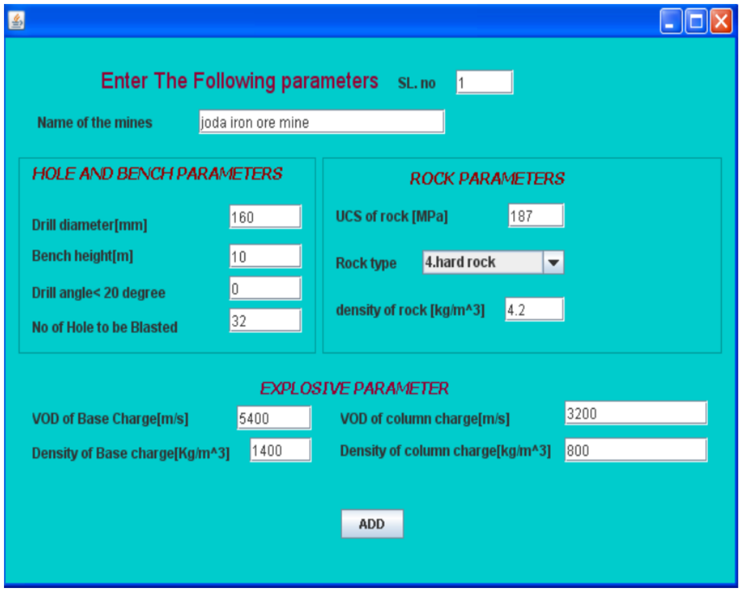
- Starting Screen:

The Starting Screen of the OCBLASTS 1.0 software serves as the initial interface presented to the user upon launching the application. It functions as the welcoming page and provides a simple, intuitive environment to begin interaction with the program. This screen plays a crucial role in guiding the user through the initial steps required to access or enter data into the system.

Upon launch, the application displays a welcome message along with an "OK" button, which the user must click to proceed. Clicking this button transitions the user from the welcome screen to the input data page, where all essential blasting parameters can be entered manually for analysis and computation.

- Add Page:

The Add Page in the OCBLASTS 1.0 software serves as the primary interface for inputting and storing new blasting data into the application's database. It allows users to systematically enter a comprehensive set of parameters required for surface blast design and further computational analysis. This page is designed with structured input fields, data validation mechanisms, and secured access to ensure both accuracy and data integrity.Each of these input fields is integrated with input validation checks to prevent the entry of invalid or out-of-range data. This ensures that the calculations performed using this data are both reliable and meaningful. In case of incorrect or incomplete entries, the system prompts the user to correct the data before proceeding.Once the user has correctly filled in all required fields, clicking the "Submit" button will trigger the process of data verification and automatic addition of the input values into the existing database. The backend system stores the data in an organized manner, ready for retrieval, comparison, and use in subsequent calculations or design evaluations.



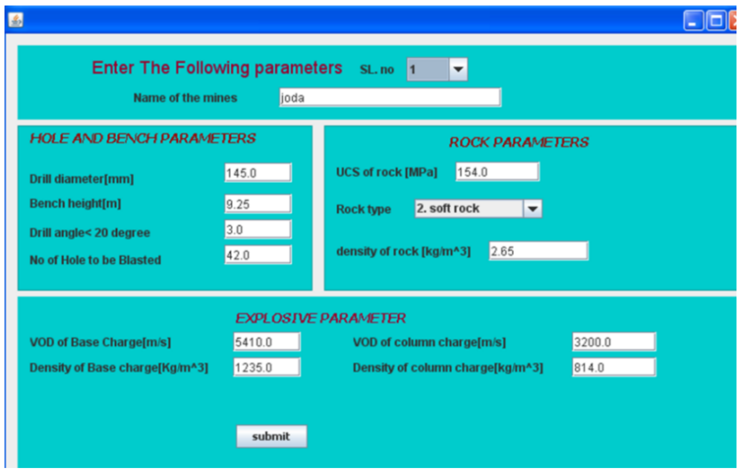
- Wrong Entry Handling and Validation Mechanism:

The OCBLASTS 1.0 software includes a robust error detection and validation system to ensure data integrity during the data entry process. This system is particularly active on the Add Page, where users input critical blasting parameters. It is designed to identify and handle various types of incorrect or inappropriate inputs, thereby minimizing the risk of computational errors and improving user experience.If a user makes an invalid entry while entering data into the form—such as inserting an incorrect value, leaving a field blank, or entering data in an inappropriate format—the application will immediately respond with a relevant error message box. The validation system operates field-by-field, checking one parameter at a time to avoid overwhelming the user with multiple simultaneous error messages.

- Input Page:

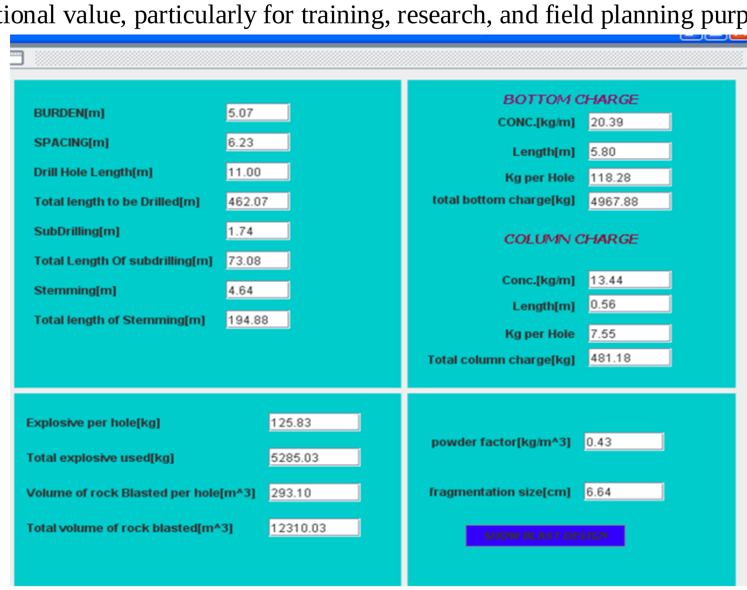
The Input Page of the OCBLASTS 1.0 software serves as a critical interface that enables users to select and utilize pre-existing blasting data stored in the system's internal database. This functionality is designed to facilitate quick access to previously designed blast parameters without the need for manual re-entry, thereby enhancing efficiency and consistency in the blast design processUpon accessing the Input Page, the user is presented with a drop-down combo box that displays a list of serial numbers, each uniquely associated with a previously stored dataset. These datasets represent different mine locations or specific blasting configurations and are retrieved in real-time from the backend Microsoft Access database file (ocblast.accdb).

Each selection in the combo box corresponds to a complete record of blast design parameters, including hole geometry, rock properties, explosive characteristics, and bench configurationsImportantly, the Input Page is read-only in nature. Users are not allowed to modify, edit, or delete the retrieved data from this interface. This design choice ensures the integrity and security of stored information, particularly in environments where consistent use of verified data is essential for safety and performance After selecting the desired serial number from the combo box, the user can proceed by clicking the "SUBMIT" button. Upon submission, the software fetches the corresponding dataset from the database, performs the necessary calculations using the embedded blast design algorithm, and then transitions to the Result Page, where the output values (e.g., burden, spacing, stemming, explosive quantity, powder factor, fragmentation size, etc.) are displayed in a structured formatThis page acts as the central access point for utilizing stored designs and supports the rapid evaluation of multiple scenarios, especially useful in field applications and iterative design processes.



- Output Page:

The Output Page of the OCBLASTS 1.0 software serves as the final interface in the blast design workflow, where the computed results of the blasting operation are presented to the user in a clear and organized format. This page is displayed immediately after the user submits the input data or selects a dataset from the database via the Input Page.Special emphasis is given to the distribution of explosive energy, as the page provides a clear breakdown of the bottom charge and column charge, detailing how the total explosive charge is distributed along the depth of the blasthole. This information is crucial for optimizing energy confinement, improving fragmentation, and minimizing ground vibration.Although the current version focuses on numeric and textual output, the future version of OCBLASTS 1.0 is proposed to include graphical features, such as blast pattern visualizations, charge distribution diagrams, and 3D graphical representations of blastholes and benches. These enhancements will significantly improve the software's usability and educational value, particularly for training, research, and field planning purposes.



III. CONCLUSION

Extensive reviews have been conducted on the parameters affecting surface blast design, leading to the identification of key factors that significantly influence blast performance. Several researchers, such as Langefors and Kihlstrom, Lopez & Jimeno, Ash, Bhandari, Singh & Sarma, Thote& Singh, and Andersen, have contributed to the evolution of various empirical and theoretical blast design methods. Among these, the blast design theory by Langefors and Kihlstrom (1978) is the most widely recognized and applied. Although this approach delivers precise and dependable results, it involves complex and time-intensive calculations when carried out manually.Recognizing this limitation, the need was felt to develop a user-friendly computer-based application that would assist blasting engineers in quickly and efficiently arriving at optimized blast designs. In response, the OCBLASTS 1.0 software was developed, integrating essential design parameters into a structured computational tool. The software interface is intuitive, and the application is easy to operate, even for users with limited programming knowledge.The current version of the software accepts input through the keyboard and enables the export of both input and output data into text files for documentation or further analysis. The software considers a wide range of parameters including rock characteristics, explosive properties, and bench configurations, ensuring a comprehensive and realistic modeling of surface blasting scenarios. Although the software relies on empirical relationships and thus has some limitations in its applicability across all field conditions, it has been successfully tested in two operational mines—a coal mine in Odisha (Orissa) and an iron ore mine in eastern India. The software's predictions, especially regarding the blasted rock volume, powder factor, and fragmentation size, closely aligned with actual field data, confirming its accuracy and practical utility.To enhance usability and extend functionality, a graphical version of the software was also developed using Java within the NetBeans IDE. This version incorporates a database system, making data handling faster and more efficient. The inclusion of a database also enables users to save, retrieve, and manage multiple design scenarios conveniently, reducing manual input time and allowing for multiple iterations to arrive at the best possible solution.In conclusion, OCBLASTS 1.0 marks a notable advancement in the digitalization and simplification of surface blast design. With continued enhancements, such as incorporating new explosive types, advanced drilling techniques, and modern blasting configurations, the software has the potential to evolve into a highly dynamic and versatile tool capable of meeting the requirements of various mining environments and operational conditions.

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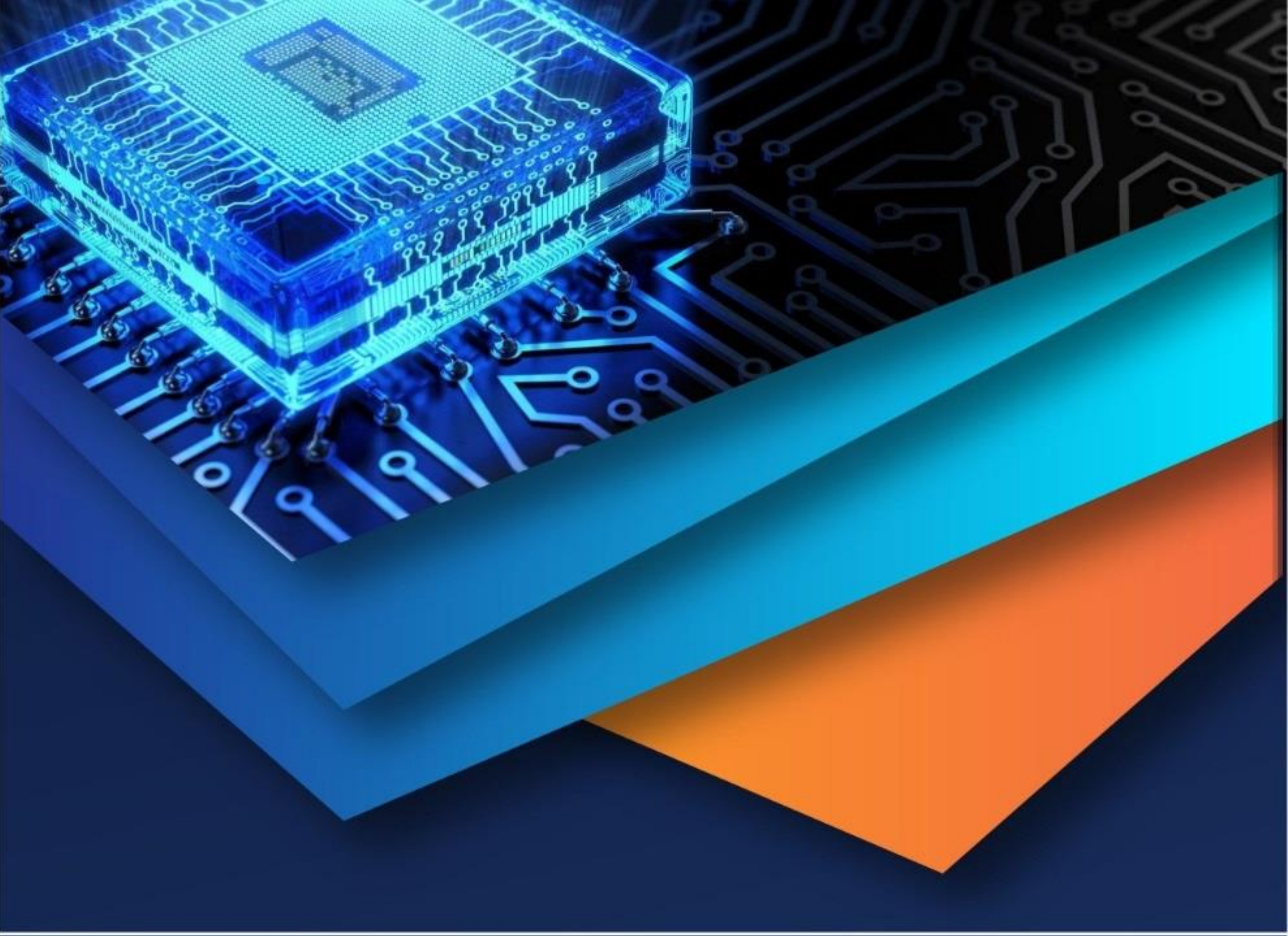

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