Critical Parameters Influencing Opencast Mine Design - A Review

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Abstract: Open cast mining plays a crucial role in extraction of ore/coal compared to other methods due to its economical and operational advantages. However, the success of opencast operations mainly hinges on the accurate designing of the mine pit, which consider multiple parameters influencing the designing. This review provides the key parameters that engineers must consider while designing open pit mines which also includes the parameters that effect the design and operational efficiency of open cast mines. By integrating geological, geotechnical, geometric, economical, operational methods and environmental considerations, etc, the designing of pit can be done reliably. This paper aims to provide a holistic understanding of their interdependencies, standards employed for their assessment, and their collective impact on achieving economically viable, safe, and environmentally responsible mining operations throughout the mine life cycle, from initial conceptualization to post-closure.

Keywords: *Economical, Geological, Geotechnical, Geometric, Opencast, Mine Design.*

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I. INTRODUCTION

Opencast mine design is a multidisciplinary process that integrates geological, geotechnical, hydrogeological, environmental, and economic parameters to develop a technically feasible, economically viable, and environmentally sustainable mining operation. The design of a surface pit fundamentally determines the resource recovery, overall mine life, safety, and environmental performance of a mining project [4]. The determination of optimal pit limits, slope configurations, bench geometry, and haul road layouts are among the crucial decisions that directly impact production, operational and economical acts [75].

Geological parameters such as orebody geometry, lithological contacts, and structural discontinuities control the spatial configuration of the pit and the sequencing of extraction [54]. Simultaneously, geotechnical attributes like rock mass strength, shear strength parameters, and groundwater conditions influence on slope stability, bench design, and overall safety of the mining operation [70]. Incorporating hydrogeological models is also critical in regions with high rainfall or aquifers intersecting the mining area, as pore water pressure can substantially reduce slope stability [27]. Geometric parameters, including fundamental slope configurations, play a vital role in pit design. The overall geometry of an opencast mine is not determined in isolation but rather emerges from the interaction of multiple factors such as geological characteristics, economic feasibility, equipment capabilities, and regulatory requirements. Each of these parameters influences the pit configuration either directly, through constraints on slope angle, bench height, or pit depth, or indirectly by shaping operational efficiency and long-term stability. Moreover, aspects such as safety considerations, haul road placement, and ore-waste distribution further contribute to the geometric framework, making pit design a multidisciplinary process that balances technical, economic, and environmental demands. Economic and operational parameters such as ore grade distribution, stripping ratio, cutoff grade, and haulage distance further influence the shape and depth of the pit by affecting the break-even limits of ore extraction. Moreover, environmental and social factors, including land-use conflicts, dust generation, and rehabilitation requirements, are now integral to early-stage

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pit design due to stringent regulations and community expectations [8]. Despite advances in optimization algorithms and mine planning software, real-world application of pit design continues to be constrained by uncertainties in input data, trade-offs between conflicting objectives, and practical limitations in equipment and infrastructure. This review critically examines the principal parameters considered in pit designing for open cast mines, drawn from various literatures to highlight the practices and challenges.

➢ *Various Parameters Considered For Pit Design*

The designing of a pit considers various parameters which require pre-mining considerations such as geological, geotechnical, and hydrogeological conditions, while for ongoing operations, geometric, economic, and operational aspects must also be addressed. The choice of mining method, type of machinery deployed, and compliance with regulatory standards further guide the design process. Each design parameter is inherently interdependent; for instance, bench height and width are strongly influenced by the size and type of equipment used, while the overall slope angle directly impacts both the stripping ratio and the safety of mining operations. Additionally, factors such as ore-body geometry, rock mass strength, and groundwater conditions can significantly alter pit dimensions and slope stability, necessitating a balance between safety, operational efficiency, and economic feasibility. Hence, pit design is a multi-parameter optimization process where engineering judgement and software-based analysis are combined to achieve safe and sustainable mine development. The figure 1 illustrates a holistic view of the diverse parameters that govern pit design. The central circle emphasizes the core theme—various parameters considered for pit designing. Surrounding it are multiple interconnected domains, including geological, geotechnical, geometric, economic, environmental, and social aspects. Each circle signifies a domain of influence that directly or indirectly contributes to the overall design process. Geology and geotechnics define ore body structure and stability; geometric parameters guide pit configuration; economic aspects address project feasibility; while environmental and social dimensions ensure sustainable operations and societal acceptance. The circular layout has been used to highlight the equal importance and interdependence of all parameters in shaping a practical and sustainable pit design.

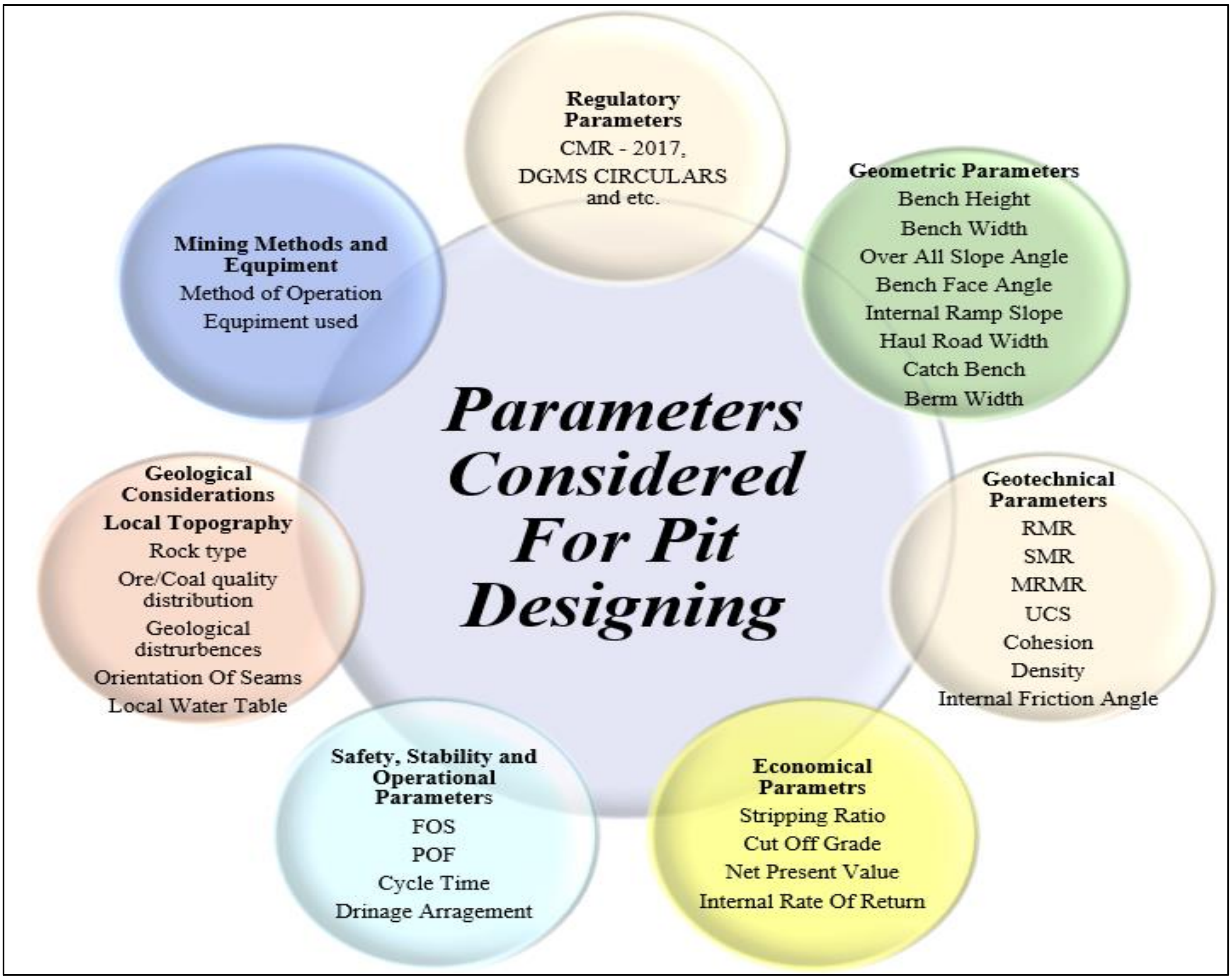

Fig 1 Various Parameters Considered for Pit Designing

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➢ *Geological and Local Topography*

The geological and local topography considerations are the major factors which influence the method of Woking and Design constraints, the geological parameters include the Rock/strata type, orientation of the strata, grade distribution, local water table, geological disturbances like faults, joints etc. Whereas local topography includes the Elevation of the surface, local water bodies, average rainfall, and surface features etc.

- *Rock or Strata Type*

The type of rock present at a mine site significantly affects the design of an opencast slope, as it influences factors such as slope angle, stability, and excavation efficiency. Strong, intact rocks like granite and basalt typically support steeper slope designs, while weaker or heavily weathered materials, such as shale or claystone, require gentler slope angles to ensure stability [78]. The blending of the various strata will affect the strength and properties of the slopes which leads to the failure of slope, and this may also affect the grade/Quality of the ore/coal. Strata with different soils are shown in the figure 2. Furthermore, rock types differ in how they interact with water: clay-rich rocks may swell and lose strength when saturated, whereas more permeable formations like sandstone improve natural drainage, which can enhance slope safety in wet conditions [20]

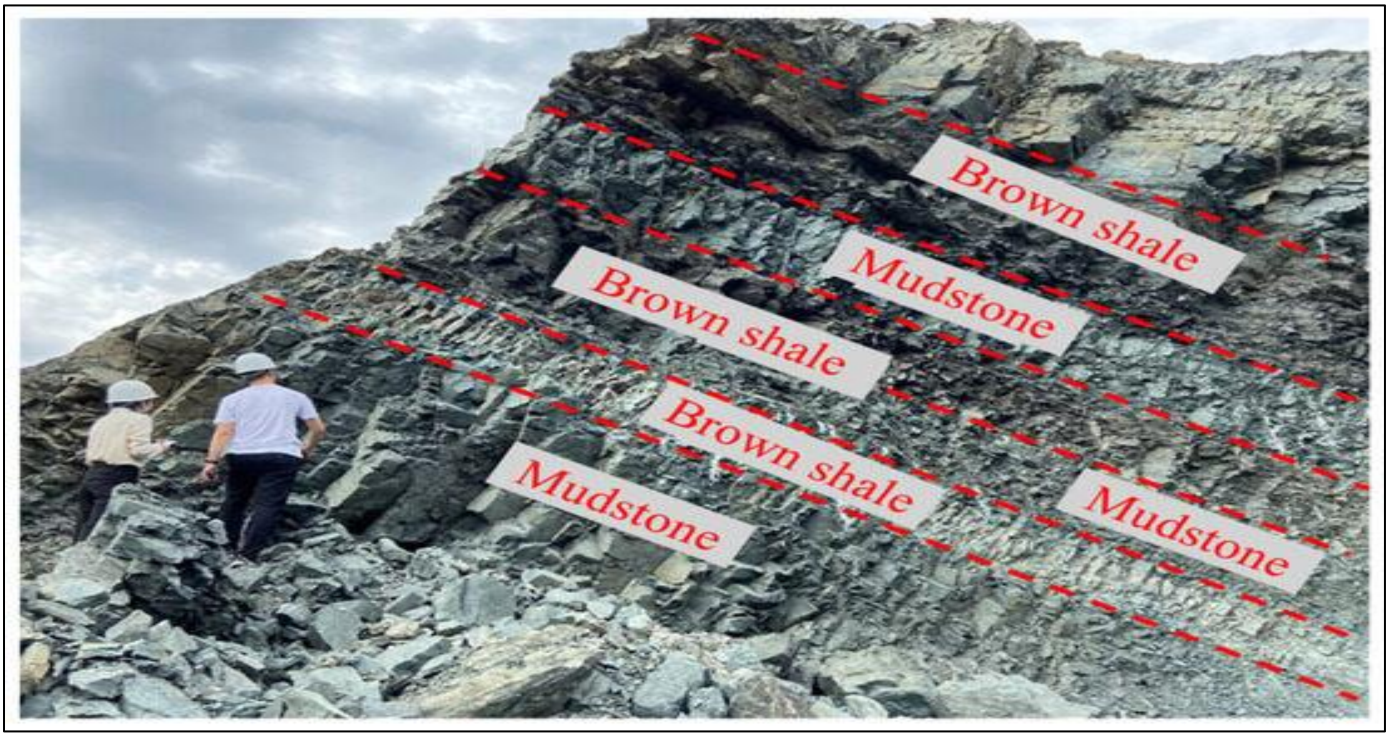

Fig 2 Local Geological Structure and Rock Stratum Distribution of the Rock Slope [49]

- *Geological Disturbances*

Geological disturbances such as faults, folds, joints, shear zones and fracture networks, have a significant influence on the design and long-term stability of opencast mines. These structures can modify the stress regime, weaken the rock mass, and alter groundwater flow paths all of which directly affect the slope performance and pit geometry [52]. Faults in particular are critical features, as they often act as zones of weakness within the rock mass as shown in figure 3. The displacement and fracturing associated with fault damage zones can reduce cohesion and frictional resistance, thereby lowering slope stability. The fault zones generate complex deformation mechanisms, which are often underestimated when using conventional slope stability analysis tools [51]. To account for this, designers frequently reduce slope angles or introduce wider berms in faulted areas to minimize the risk of failure [64]. Structural features such as bedding planes, folds, and joint sets also exert strong control on slope behavior. Stead and Wolter (2015) observed that the orientation and persistence of these features determine the type of slope failure planar, wedge, or toppling and must therefore be integrated into pit design assessments [72]. Neglecting structural controls often results in unsafe slope geometries and inaccurate predictions of failure modes. The orientation of strata and faults can further modify the in-situ stress field within pit slopes. For instance, Tan W (2014) demonstrated that inclined strata shift stress concentrations in ways that accelerate failure development [74]. In more structurally complex terrains such as fold-and-thrust belts, locked segments created by fault intersections and folds strongly influence slope failure initiation. Using UAV photogrammetry combined with discrete fracture network (DFN) and distinct element simulations, Zhan J (2025) demonstrated that these locked zones control the deformation process of coal mine slopes in western China [81]. Even in high-altitude mining environments, the presence of tectonic faults has been shown to alter slope stability conditions. Nizametdinov F, 2025 reported that geotechnical parameters, such as cohesion and internal friction angle, must be reduced in design models to reflect fault-related weaknesses. Without such adjustments, slope stability analyses may overestimate safety factors [57].

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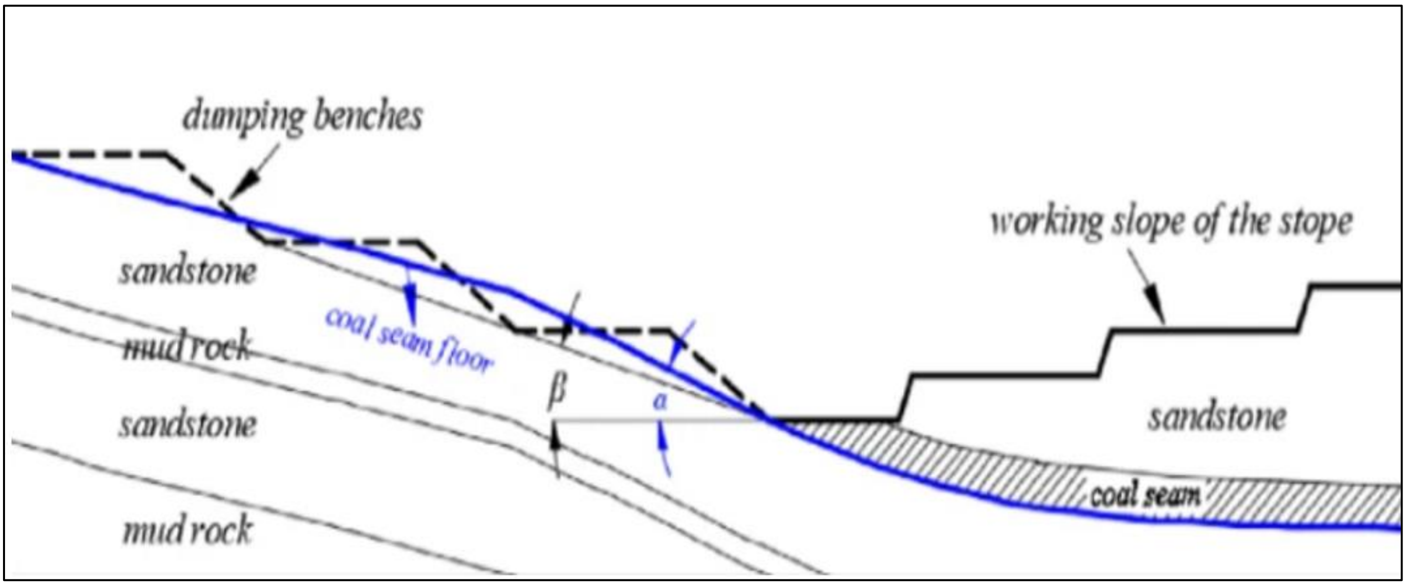

Fig 3 Simplified Cross Section of a Mine Representing the Tectonic Zone and Rift Present in the Strata's [44].

- *Orientation and Strata Distribution*

The orientation and strata distribution significantly influence the geometry and stability of pit slopes in surface mining operations which also effect on sequence of operation [25]. The key factor guiding the selection of mining methods is the stratigraphic positioning rate as shown in figure 4, which measures the ratio of the heights of the upper and lower interbeds surrounding a coal seam.

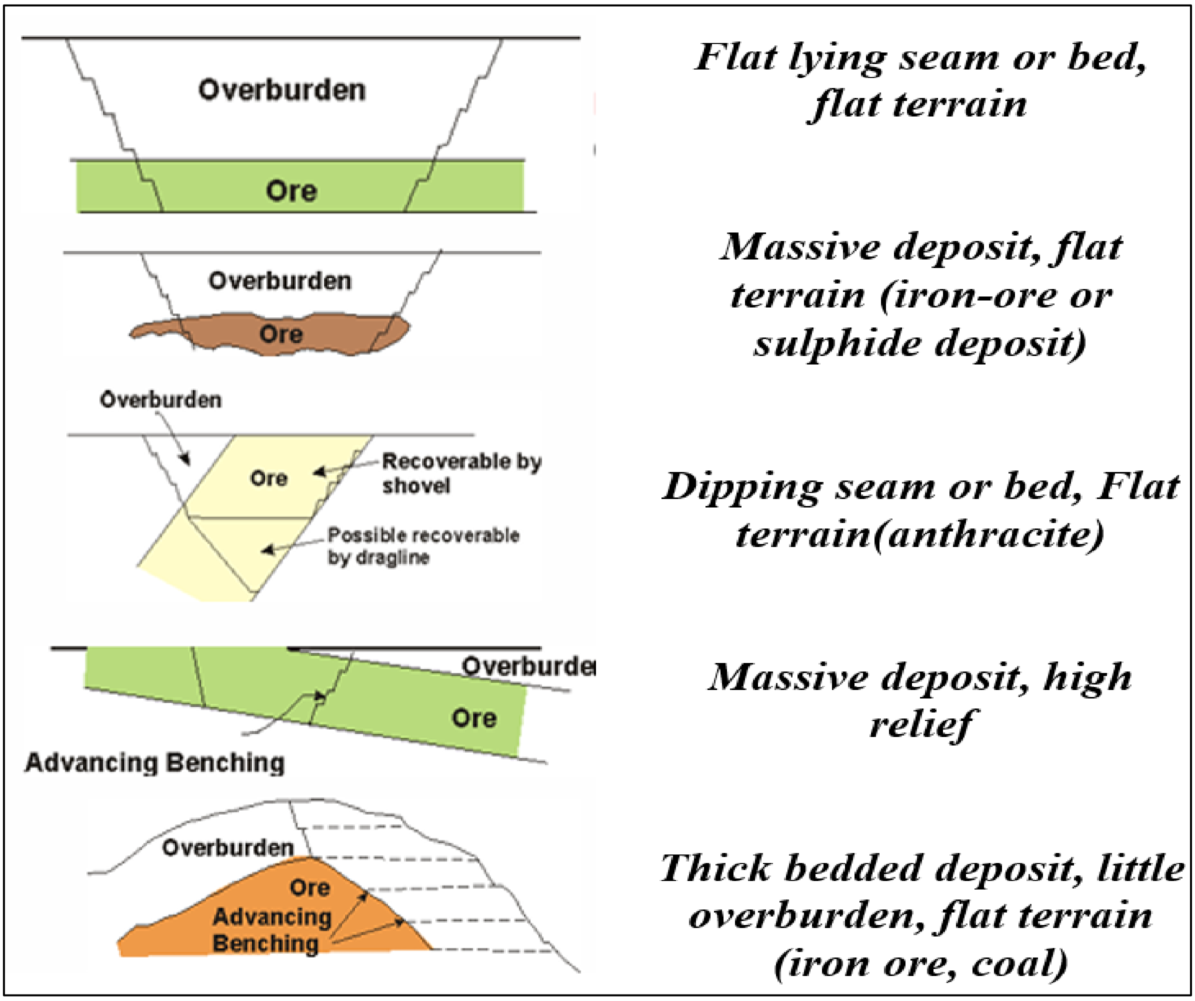

Fig 4 Representation of Ore Body Having Various Orientation Compared To the Surface [33]

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Depending on these bedding conditions, optimal excavation schemes can be selected to minimize overburden removal costs and maximize dragline efficiency [76]. Strata distribution also plays a crucial role which influence the pit design, particularly when different lithological units exhibit contrasting geo-mechanical properties. Strata consisting of various sequences of alternate hard and weak layers often requires various slope angles and requires incorporation of additional safety berms to manage stability of pit [60]. The presence of inclined rock layers as shown in figure 4, have a pronounced impact on pit design by altering the in-situ stress field, which can significantly affect slope stability and overall excavation safety. Heterogeneous stratigraphy will also result in the complex failure patterns due to difference in the properties of each stratum**.** In the area having complex structure like Haul roads, ramps are aligned parallel to the bedding as shown in figure 5 or to the mechanically stronger strata to minimize the risk of slope degradation and failure [40].

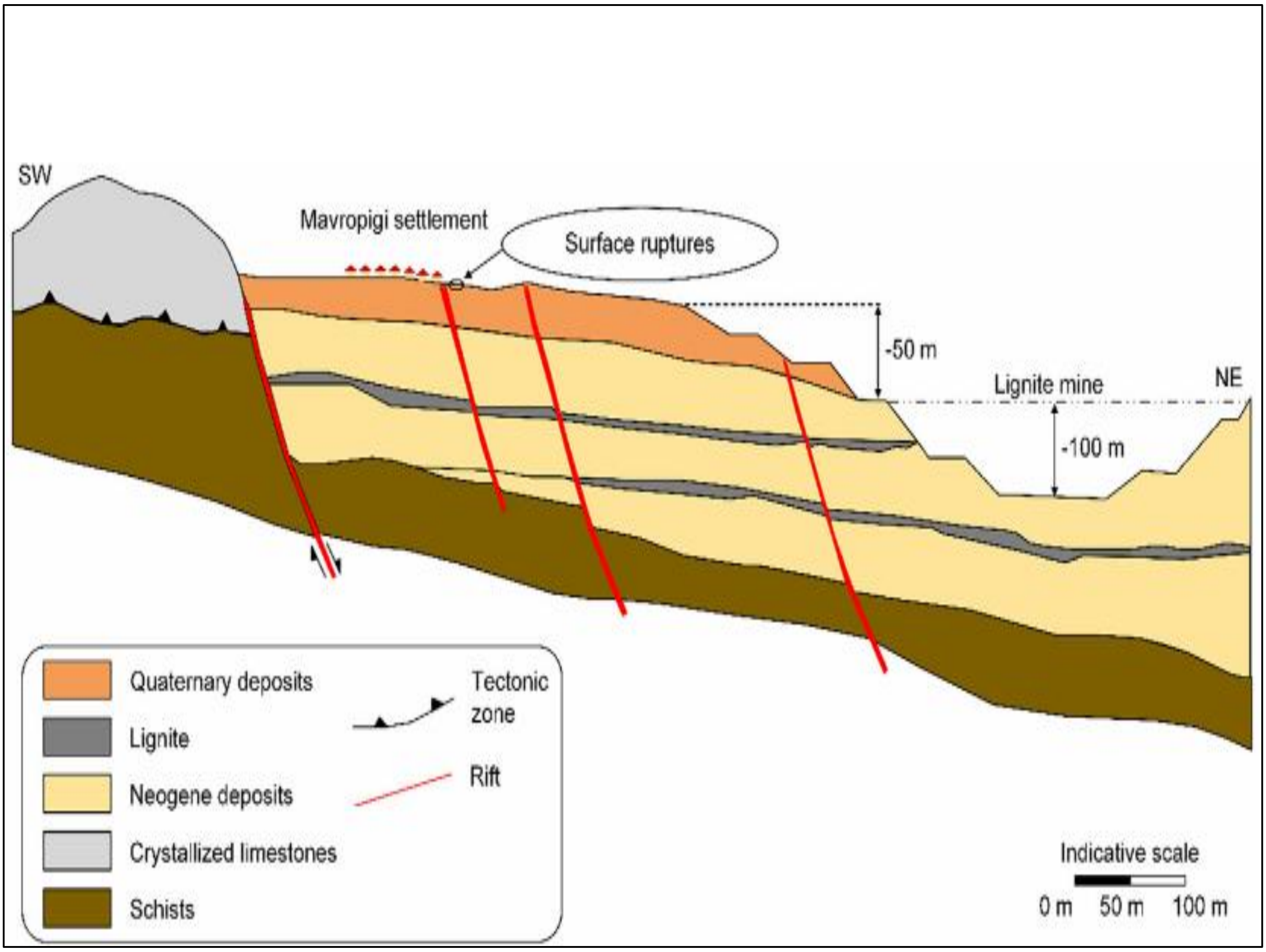

Fig.5. Distribution of Geological Strata beneath the Dumping Benches and Working Slopes [82]

- *Ground water table*

Groundwater is one of the most critical factors controlling the safety and economics of opencast mine design. Elevated groundwater levels increase pore pressure within the slope-forming material, which reduces effective stress and consequently decreases shear strength of rocks, leading to higher risks of slope failure. As highlighted by Shalaho Dina Devy (2020) groundwater inflow into pit slopes not only destabilizes rock masses but also complicates blasting operations and drainage requirements [20]. Similarly, Ghulami et al. (2021) emphasized that excavations below the water table alter hydraulic gradients and can cause significant changes in local hydrogeological conditions, potentially triggering long-term instability [28]. In addition to stability concerns, groundwater introduces major operational challenges. Excessive inflows demand continuous pumping, which increases operational costs and may alter the overall pit slope angle to maintain safety. Improperly managed groundwater also accelerates weathering of slope materials as shown in figure 6, leading to progressive weakening of pit walls over the mine life. Case studies have shown that ignoring groundwater conditions can result in premature pit abandonment or costly remediation measures [36]. In many industries monsoon arrangements are carries out to defend the rainwater runoff. Therefore, accurate hydrogeological modelling, dewatering, and reinforcement strategies are essential to integrate groundwater control into pit design for both safe and economically viable operations.

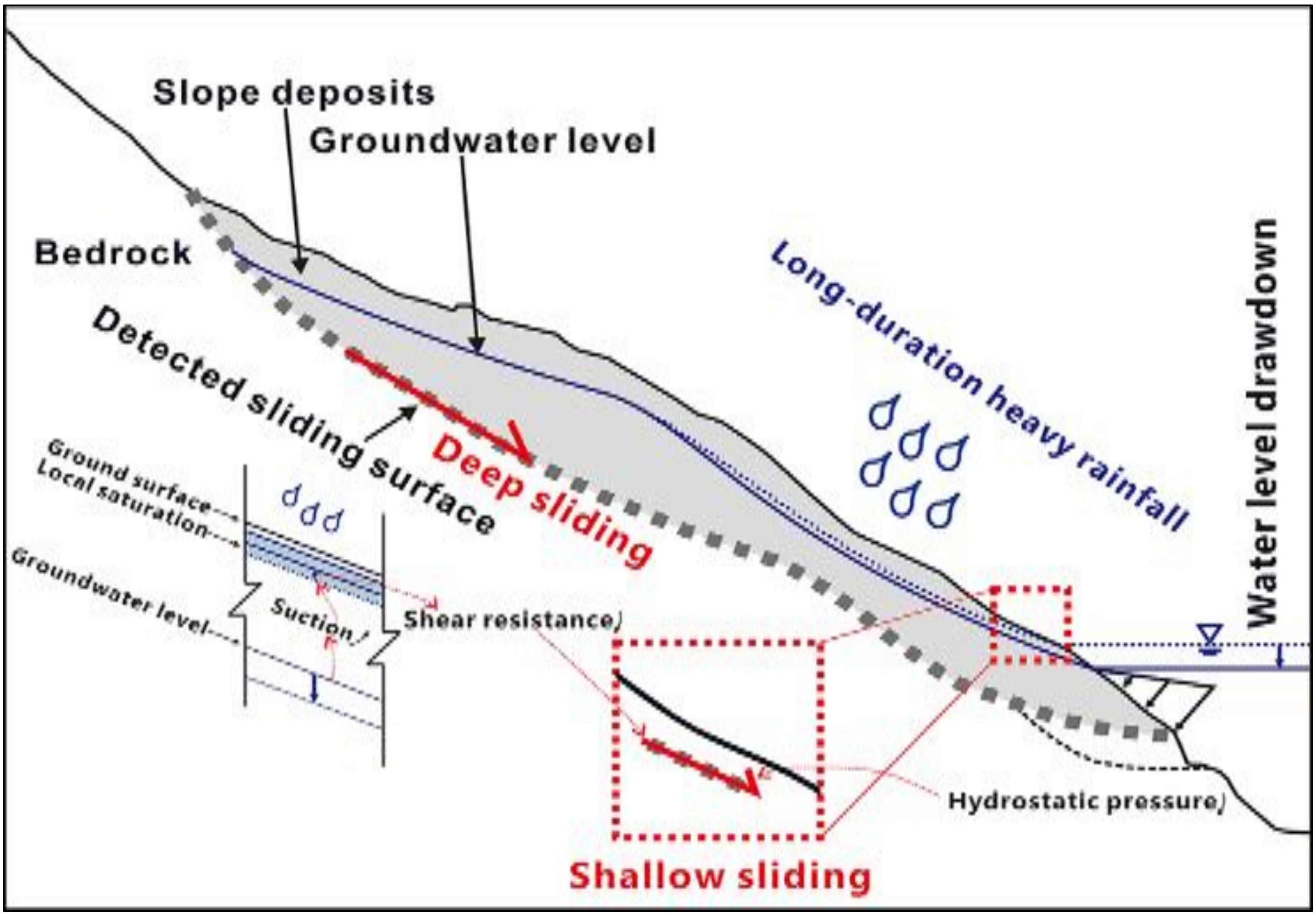

Fig 6 Behavior of Slope under the Combined Influence of Intense Rainfall and Rapid Groundwater Level Reduction [17].

➢ *Geotechnical Parameters*

- *Density*

The most direct impact of density on pit design is in the accurate estimation of mineral resources and ore reserves. Block models, which form the basis of pit design, contain information on material volumes. To convert these volumes into economically meaningful tonnages (for both ore and waste), the bulk density of each material type is essential [50]. An underestimation of density can lead to an underestimation of total available tonnage and metal content, affecting mine life and project valuation. Conversely, overestimation can lead to inflated reserve figures that are not met in production, impacting financial forecasts [73]. Therefore, precise density measurements are crucial for reliable resource and reserve calculations, directly influencing the scale of the pit.

Density also affects the selection and performance of mining equipment. Haul trucks and loading equipment are typically rated by their volumetric capacity, but their payload is determined by the density of the material being moved [58]. Denser ore or waste means a higher mass per unit volume, which can lead to equipment reaching its weight capacity before its volumetric capacity. This impacts cycle times, fuel consumption, and wear and tear on machinery. Mine planners must consider these density variations when sizing fleets and designing haul roads to ensure efficient material movement and control operational costs, which subsequently influences the overall pit dimensions and layout.

- *Cohesion*

Cohesion is the intermolecular attraction between the soil particle's which combines them to mould together to resists failure, it is based on the soil properties. A higher cohesion results in high Factor of safety and stress, strain and deformation of slope [56]. In pit design, a higher cohesion allows for steeper and higher pit slopes, which in turn reduces the volume of waste material that needs to be excavated [3; 31]. Cohesion also interacts with groundwater conditions, as pore water pressure tends to reduce effective stress and diminish cohesive resistance [68]. Ullah et al. (2025) highlighted that in dynamic slope stability analyses, cohesion loss due to combined groundwater effects and repeated blasting can significantly reduce slope reliability, often necessitating slope flattening or reinforcement measures [77]. The cohesion can be determined by the laboratory analysis of soil, which act as major parameters for designing in slope modelling. The below figure 7 represent the relation between normal stress vs shear stress impacting the cohesion.

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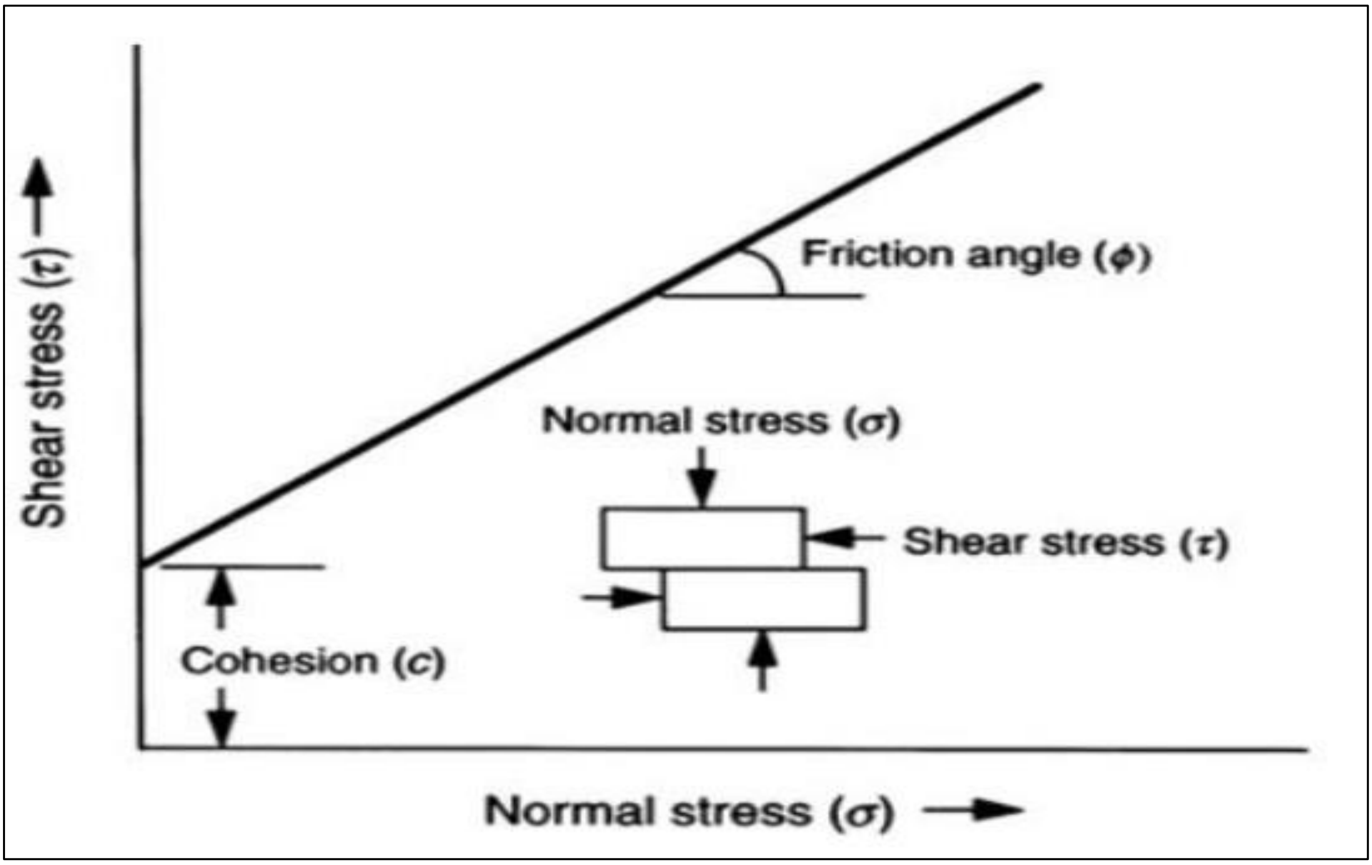

Fig 7 Relation Between the Shear Stress and Normal Stress with Cohesion and Internal Friction Angle [16].

- *Internal Friction Angle*

The internal friction angle is the angle measures between normal and resultant shear stress, It measures the ability of slope to resist shear failure. In pit design, a higher internal friction angle indicates a more competent and stable rock or soil mass, allowing for the design of steeper overall, inter-ramp, and bench slope angles [68]. This is economically advantageous as steeper slopes reduce the volume of waste material that needs to be excavated to access the ore, thereby lowering the stripping ratio and mining costs [1].

- *Rock Mass Rating (RMR)*

The RMR parameters provide a quantitative assessment of rock mass based on the combined factors like Uniaxial compressive strength, RQD, joint spacing, joint condition, groundwater, and orientation of discontinuities [13], are individually assessed through field and laboratory investigations in different sections of the proposed pit walls. The RMR classification gives an idea about the strata condition by providing an rating based the previous five parameters. A higher RMR value indicates better quality rock, signifying greater stability. In pit design, this translates directly to the ability to design steeper overall, inter-ramp, and bench slope angles [11].

Steeper slopes are economically beneficial as they reduce the volume of waste material that needs to be excavated, thus lowering the stripping ratio and mining costs [29]. Conversely, a lower RMR value points to poorer quality rock, necessitating flatter slopes to ensure stability, which results in a larger pit footprint and increased waste stripping volumes [67].

- *Slope Mass Rating (SMR)-*

Slope Mass Rating is a modified RMR system for slope, developed by Romana (1985). SMR is a useful rating tool for evaluation of slope instability risk based on slope face relation with geological discontinuities.

$$SMR = RMR + (F1.F2.F3) + F4.$$

The adjustment rating of joints is the product of three factors:

F1 depends upon the parallelism between joints and slope face strike. It ranges from 1.0 to 0.15. The values are empirically established by the formula:

$$F1 = (1 - \text{Sen}\,|A|)^2$$

Where as,

Where A is the parallelism between discontinuity and slope strikes and B is the discontinuity dip (βj).

F2 refers to the joint dip angle in the planar mode of failure. Its values range from 1.00 to 0.15. The empirically established formula is

$$F2 = \tan^2 Bj$$

Where Bj = joint dip angle.

F3 indicates to the relationship between slope face and joint dip. In planar mode of failure, F3 refers to the probability of joints daylighting on the slope face. Condition is favorable when slope face and joints are parallel and unfavorable when slope dips 10 degree more than joints. F4 - Adjustment factor for method of excavation has been fixed empirically and are follows Natural slope = +15, Presplitting = +10, Smooth blasting = +8, Normal blasting = 0, Deficient blasting = -8 and Mechanical excavation = 0. According to the SMR values, Romana (1985) defined five stability classes. They are described in Table 1.

Table 1 Stability Classes as per SMR Values (Romana, 1985) [62]

Class	**V**	**IV**	**III**	**II**	**I**
SMR Values	0-20	21-40	41-60	61-80	81-100
Rock mass description	Very Bad	Bad	Normal	Good	Very good
Stability	Completely unstable	Unstable	Partial stable	Stable	Completely stable
Failures	Big planar or soil like or circular failure	Planar or big wedges	Planar along Some joints and many wedge failure	Some block failure	No failure
Probability of failure	0.9	0.6	0.4	0.2	0

- *Modified Rock Mass Rating (MRMR)*

The Modified Rock Mass Rating (MRMR) system, developed by Laubscher, extends Wieniawski's RMR classification by incorporating adjustment factors specific to mining environments, such as blasting effects, weathering, and excavation-induced stress changes [42]. These adjustments make MRMR particularly suitable for assessing long-term slope stability in opencast mines, where exposure to dynamic operational and environmental conditions can progressively degrade rock mass quality [18]. Low MRMR values necessitate flatter slopes to ensure safety, leading to larger pits and increased costs [23]. By incorporating factors like blasting damage and stress, MRMR helps optimize slope angles for both safety and profitability, directly shaping the final pit geometry [42;46]. The below figure 8 represents the relation between MRMR and Slope height.

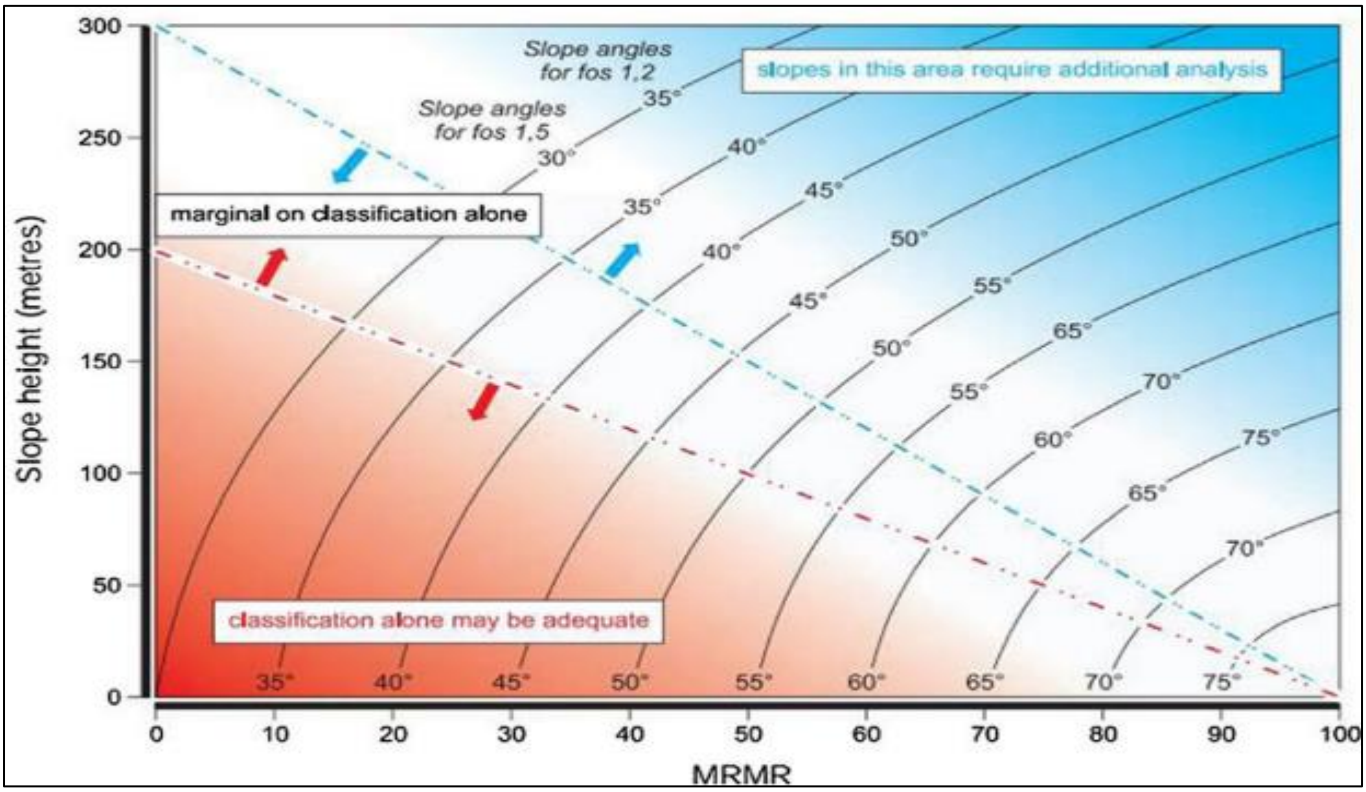

Fig 8 Empirical Slope Design Chart (Haines And Terbrugge, 1991) [32]

- *Uniaxial Compressive Strength (UCS)*

The uniaxial compressive strength (UCS) of rock and soil is a fundamental parameter in geotechnical slope design, directly influencing the estimation of shear-strength parameters, factor of safety, and overall stability of slopes. It is a fundamental input for both empirical and numerical methods of slope stability analysis [41]. The UCS value helps determine the material strength classification, which in turn influences the overall slope angle, bench design, and safety factor calculations. Typically, higher UCS values indicate stronger, more stable rock masses capable of supporting

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steeper slopes, whereas lower UCS values necessitate more conservative designs to avoid failure [37].

For instance, in empirical design methods such as the Slope Stability Probability Classification (SSPC) or RMR (Rock Mass Rating) systems, UCS is one of the primary parameters contributing to the strength rating of the rock mass. According to Hoek et al. (2002), UCS is also directly used in the Hoek-Brown failure criterion, which is widely applied in numerical modeling for slope stability [26]. The criterion uses UCS along with parameters like GSI (Geological Strength Index) and mi (material constant for intact rock) to estimate rock mass strength [24; 26].

➢ *Geometric Parameters*

- *Bench Height and Bench Width –*

Bench height is the vertical distance between the upper and lower bench surface whereas, Bench width is the distance between the crest and the toe measured along the upper surface [79]. The height and width of the bench are determined by various parameters like Machinery deployed, Production required, Economical constraints (stripping ratio). As per the Coal Mines Regulations (CMR) -2017 the bench height and width are considered as follows:

The height of benches in coal and overburden of rock formation shall not be more than the digging height or reach of the excavation machine in use for digging, excavation or removal, and the width thereof shall not be less than - (a) the width of the widest machine plying on the bench plus two meters; or (b) if dumpers ply on the bench, three times the width of the dumper; or (c) the height of the bench[21]. Although the parameters mentioned followed it may or may not provide an required Factor of safety of slopes. Generally, for open cast mines, the safety factor used is in the range of 1.2 – 1.4 [71]. According to the DGMS (tech.) circular no. 03 of 2020, guidelines for scientific study under regulation 106 of coal mines regulation, 2017, the minimum factor of safety to be considered for design of pit, bench & dump slope shall not be less than 1.50 for permanent slope and 1.30 for other slopes.

- *Bench Face Angle*

The Bench face angle (BFA) is a critical component of open cast mine slope geometry. It refers to the inclination of the individual bench face (the exposed vertical or inclined surface of the bench) measured from the horizontal as shown in figure 9. It is typically expressed in degrees and directly influences the stability, drainage, and safety of pit walls. The greater the angle the less will be the stability [65]. The bench height and width are the major parameters influence the slope, the majority of problem is to maintain an optimal relation between the Height, width, Slope angle and Factor of safety. According to DGMS, the overall slope angle of any mine should not be greater than 45°. As the curvature of the slope has a deep effect on slope stability, it should be avoided in slope design [65].

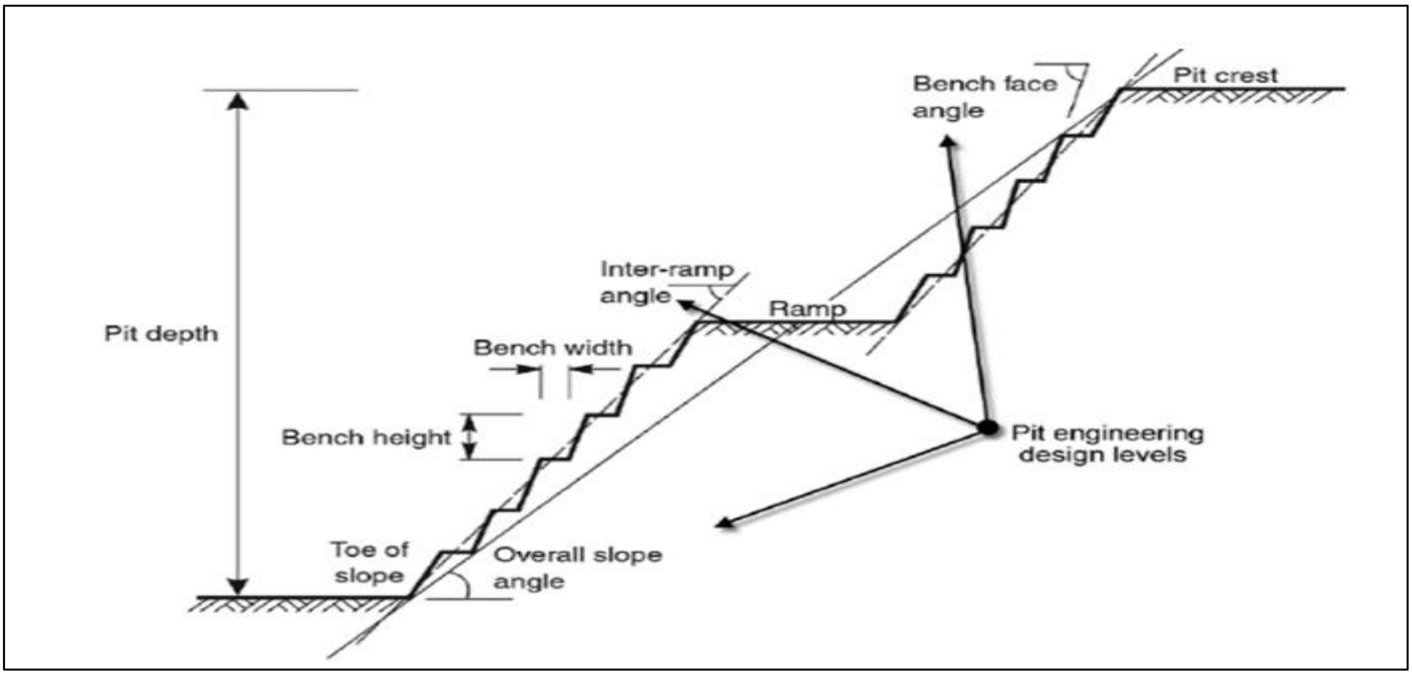

Fig 9 Schematic Diagram Showing Opencast Bench Slope Parameters [30].

- *Overall Slope Angle*

The overall slope angle is the angle made by an imaginary line joining the top most bench crest to the bottom most bench toe as shown in figure 9. It integrates all the bench geometry, as the bench height increases the overall slope angle also increases whereas with increase in the width the overall slope angle decreases with respect to each. Steeper angles reduce waste rock excavation, lowering costs and increasing project [31]. However, overly steep slopes heighten the risk of dangerous instabilities, compromising safety and production [1]. Therefore, pit designers must carefully optimize these angles based on rigorous geotechnical analysis to ensure both profitability and operational safety [35]. The aim is always to find the steepest stable slope for maximum economic return.

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- *Internal Ramp Angle and Catch Bench-*

The Inter-Ramp Angle (IRA) is the angle measured between the horizontal and a straight line connecting the toes and crests of multiple successive benches—excluding any haul roads or wide berms. It represents the average inclination of a continuous section of pit wall and is intermediate between the bench face angle and the overall slope angle.

A decoupling bench or catch bench in opencast mining is a horizontal ledge on the pit slope designed to catch falling rocks and improve slope stability [19], as demonstrated in Figure 9. Increasing the number or width of catch benches reduces the overall slope angle (making slopes gentler), which enhances safety but increases the stripping ratio by requiring more waste removal. Optimizing catch bench spacing balances slope stability and mining economic [63]. The below figure 10 represents the catch bench incorporated in the Designed pit

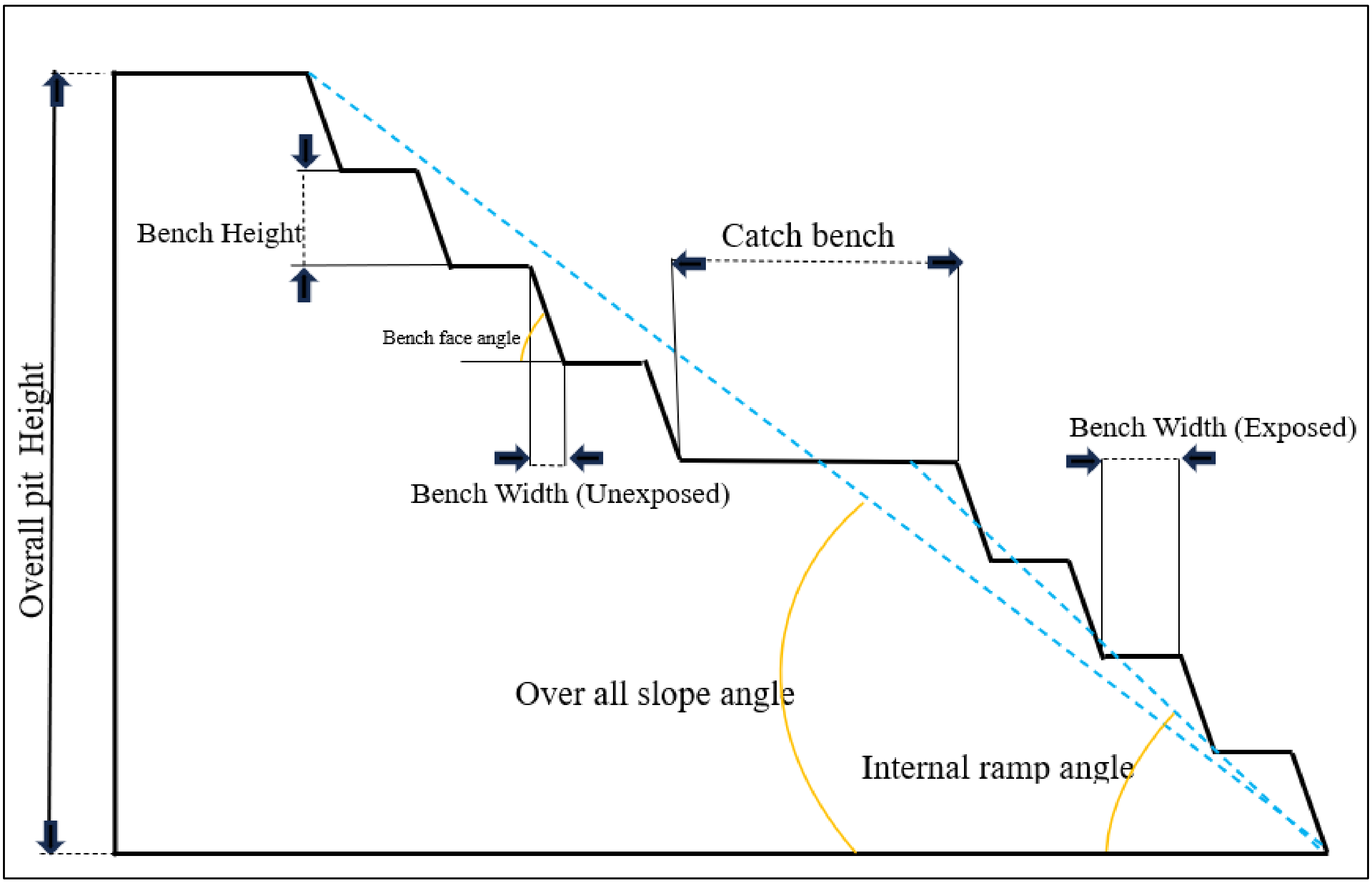

Fig 10 Representation of Catch Benches

➢ *Mining Methods and Equipment*

The chosen mining method, whether conventional drill-and-blast or continuous surface mining systems, fundamentally affects the pit's geometrical parameters. For instance, drill-and-blast operations, common in hard rock, determine bench heights, bench face angles, and the overall slope angles of the pit walls, all of which are optimized to balance safety and stripping requirements [53]. The size of loading and hauling equipment, such as large hydraulic excavators and ultra-class haul trucks, necessitates wider ramps and larger working benches to ensure efficient maneuverability and optimal productivity [22;5]. Conversely, smaller equipment might allow for narrower ramps and smaller benches, potentially reducing waste removal but at lower production rates [9]. As noted by Hustrulid et al. (2013), the selection of mining method is one of the earliest and most critical decisions in surface mine planning, as it governs the shape and operability of the pit throughout its life cycle [79]. The below figure 11 represents the sequence of extraction based on the seam inclination.

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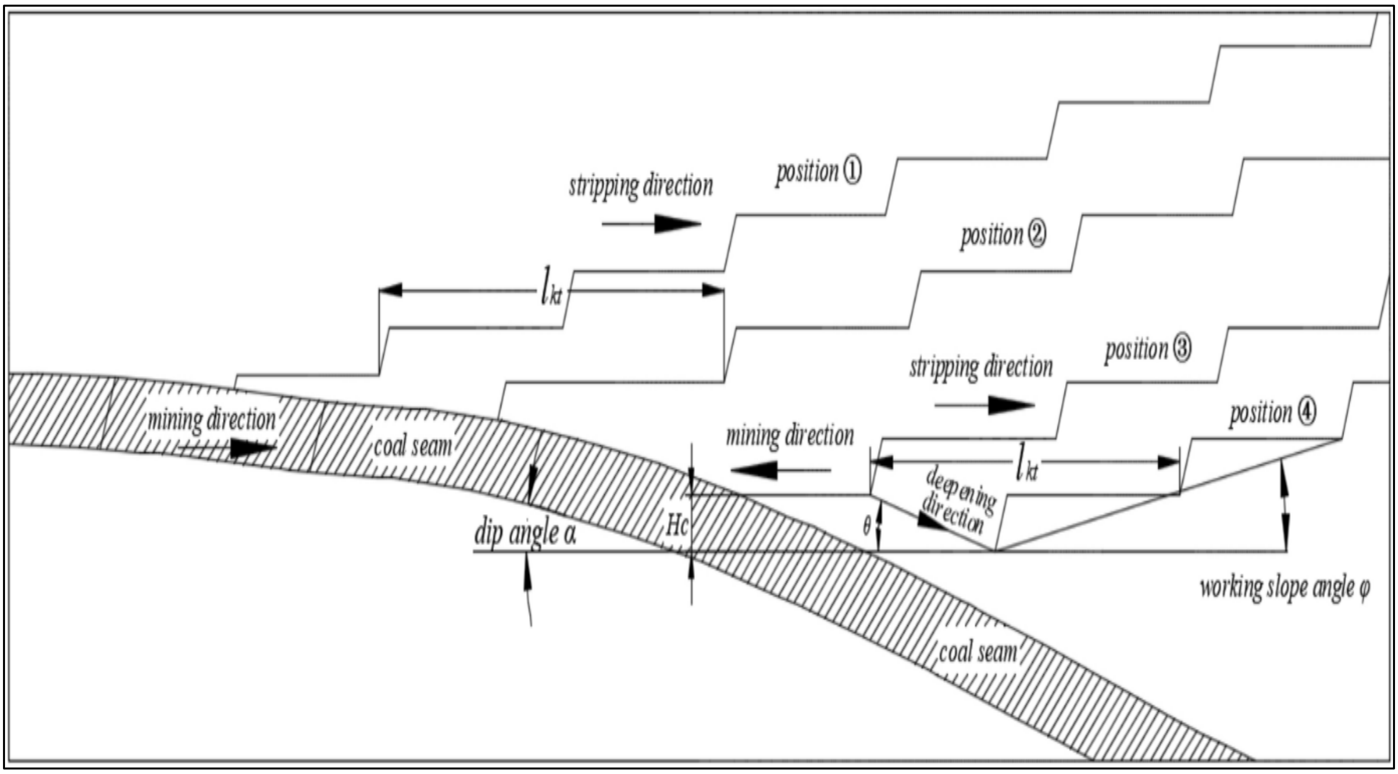

Fig 11 Extraction Sequence Compared To the Strata Orientation [82]

➢ *Economic Parameters*

- *Stripping Ratio-*

The stripping ratio (SR), defined as the volume or tonnage of overburden removed per unit of ore mined, is a crucial determinant in open pit design as it directly influences both economic feasibility and pit geometry. A higher SR implies increased removal of waste material, which escalates operating costs and may render deeper mining uneconomical. Consequently, pit limits are often constrained to optimize the balance between ore recovery and waste handling costs. As per Hustrulid and Kuchta, the ultimate pit limit is determined where the cost of removing additional overburden equals the revenue from additional ore, highlighting the pivotal role of SR in economic block modelling [39]. Lerch's and Grossmann proposed a mathematical algorithm to determine pit limits by maximizing net value, which inherently integrates the stripping ratio as a controlling factor [48]. Moreover, Bhattacharya emphasize that SR impacts decisions related to pushback design, haul road layout, and bench configuration, especially in stratified deposits [12]. The pit slope angle and depth are also indirectly affected, as steeper slopes may reduce SR but increase the risk of instability, which necessitates geotechnical compromise [59]. Additionally, the SR threshold varies across commodities and geologies; for instance, coal mines can tolerate lower SRs compared to metal mines due to thinner seam structures and high-volume extraction [66]. Hence, the stripping ratio not only governs the economic limit of excavation but also significantly affects the technical design and operational planning of open cast mines.

- *Cutoff Grade*

The cutoff grade is the minimum grade of ore/coal at which the cost of mining and processing is equal to the selling cost. The material above cutoff grade is considered for processing and below the cutoff grade is considered aa waste. According to Hustrulid and Kuchta (2006), the cut-off grade significantly affects pit optimization algorithms by altering the block value distribution, which ultimately reshapes pit geometry and depth through economic block modelling [40]. A higher cut-off grade generally leads to a smaller pit and reduced mineable reserves, as only higher-grade material is processed [43]. Conversely, a lower cut-off grade expands the pit, increasing reserves but potentially raising the stripping ratio and processing lower-grade material [7]. Ultimately, the chosen cut-off grade directly influences the mine's economic viability, production rate, and overall lifespan [6].

- *Net Present Value and Internal Rate of Returns –*

In opencast mine planning and design, economic evaluation criteria such as Net Present Value (NPV) and Internal Rate of Return (IRR) play a pivotal role in decision-making. NPV is the most widely adopted objective function, as it incorporates the time value of money and provides a reliable measure of a project's economic viability. Maximizing NPV ensures that mining schedules prioritize higher-grade ore extraction in the early years of operation, thereby accelerating capital recovery and enhancing project profitability [10]. A positive NPV signifies that the discounted revenues outweigh costs, justifying the feasibility of the mine. Conversely, a project with a negative NPV is considered uneconomic and is generally rejected.

The choice of cut-off grade, ultimate pit limit, and production scheduling are all highly sensitive to NPV. For instance, higher discount rates increase the cut-off grade, leading to shorter mine life but higher immediate cash inflows, whereas lower discount rates extend mine life by enabling the exploitation of lower-grade ore [45]. This trade-off highlights the integral connection between mine design parameters and economic evaluation tools.

Similarly, IRR is a complementary measure that reflects the rate of return at which the NPV becomes zero. While IRR is less robust than NPV for projects with irregular cash flows, it remains important in mine planning as it allows comparison of competing investment options, especially under capital-constrained conditions [2]. A project is generally acceptable if its IRR exceeds the minimum required rate of return or the company's cost of capital. In pit optimization studies, IRR provides insight into the risk-return profile of different designs and schedules, enabling engineers to balance profitability with operational sustainability [7].

➢ *Environmental & Regulatory Compliances*

Environmental and regulatory considerations are integral to the design of modern opencast mines. Beyond geotechnical and economic factors, mine layouts must comply with national mining laws, environmental protection standards, and social license requirements. These compliances influence almost every stage of design, from the determination of pit limits to waste dump placement and mine closure planning.

Environmental standards typically address land disturbance, water management, waste handling, dust and noise emissions, and the preservation of biodiversity. Incorporating these aspects into pit design often requires the inclusion of buffer zones, reduced slope heights, or restricted pit expansions to protect sensitive ecosystems or nearby settlements [47]. Such measures may reduce the achievable ore recovery, but are necessary for regulatory approval and long-term project sustainability.

Regulatory frameworks also dictate mine reclamation and closure obligations, which must be integrated into design at the early stages. For example, in many jurisdictions, operators are legally required to prepare detailed mine closure plans and provide financial assurances to ensure post-mining land rehabilitation [34]. These requirements influence not only the ultimate pit configuration but also the scheduling of waste backfilling and the design of tailings and overburden facilities.

➢ *Other Parameters*

- *Water Management*

Water within the rock mass significantly reduces the shear strength of slopes by increasing pore water pressure, which in turn decreases the effective normal stress on potential failure planes. High pore pressures can lead to instability of pit walls, causing localized failures or even large-scale slope collapses, as documented in numerous geotechnical incidents [55]. An effective drainage system, involving dewatering wells, sumps, and perimeter ditches, is designed to lower the groundwater table and remove surface runoff, thereby maintaining or increasing the effective strength of the rock mass, allowing for steeper and more economical pit slope angles [14; 15].

- *Blasting Parameters*

Blasting is a vital operation in opencast mining, serving as the primary method for rock excavation and fragmentation. However, the effectiveness of blasting depends on the optimization of key parameters such as burden, spacing, stemming length, whole diameter, and maximum charge per delay. These parameters not only determine fragmentation efficiency but also directly affect slope stability, overall pit design and ultimately economic impact [61].

Yu et al. (2020) highlighted that poorly designed blasting patterns can lead to excessive back-break and overbreak, which reduce slope stability and increase the risk of rockfalls along the final walls of an open pit [80]. They emphasized that optimized burden and spacing improve fragmentation, minimize damage to slope faces, and ensure safer long-term pit operations. Similarly, Singh (2005) demonstrated that controlled blasting methods, such as presplitting and smooth blasting, can significantly reduce blast-induced damage, thereby enabling steeper and more economical slope angles in opencast designs [69].

The dynamic effects of blasting must also be considered in slope stability analyses. Hudaverdi (2012) observed that blast-induced ground vibrations, quantified using Peak Particle Velocity (PPV), play a decisive role in controlling bench face integrity. His research suggested that when PPV values exceed critical thresholds, structural discontinuities are aggravated, reducing the factor of safety and necessitating slope flattening in pit designs [38]. Recent studies by Ullah et al. (2025) further confirmed that parameters such as burden and stemming length strongly correlate with slope stability under dynamic conditions [77]. Their findings revealed that an increase in burden significantly decreases the factor of safety ($r = -0.81$), while insufficient stemming length amplifies vibration intensity, highlighting the necessity of designing blast patterns that balance fragmentation efficiency with geotechnical safety.

II. CONCLUSION

Designing an opencast mine is not a single-dimensional task but rather a multidisciplinary effort where geological, geotechnical, hydrogeological, operational, and economic aspects must work together to ensure safety and profitability. This review shows that factors such as rock type, cohesion, internal friction angle, groundwater levels, blasting parameters, and financial measures like NPV and IRR are deeply interconnected. Their combined influence ultimately governs slope stability, pit geometry, and the overall efficiency of mining operations. Among these, groundwater and environmental regulations stand out as decisive elements since they often impose constraints that require significant design adjustments. Ignoring the interaction between these parameters can result in unstable slopes, high stripping ratios, or uneconomical operations. On the other hand, a well-integrated approach using tools like advanced numerical modelling, geostatistical techniques for reserve estimation, and multi-criteria decision-making can produce pit designs that are both technically reliable and environmentally responsible. Looking to the future, the adoption of real-time monitoring, improved simulation models, and sustainability-focused indicators will be crucial in modern pit design. These developments will not only enhance operational safety and cost-effectiveness but also ensure that mining practices remain aligned with global expectations for sustainable and responsible resource extraction.

FUTURE SCOPE AND RECOMMENDATIONS

Although significant progress has been made in understanding the parameters influencing opencast mine design, several areas remain open for future investigation. Advances in 3D Geological modelling and 4D geological modelling (The modelling which adds the Time Dimension, allowing for the simulation of geological processes and their evolution over time), coupled with machine learning and artificial intelligence, and could provide more accurate reserve estimation and pit optimization. Real-time monitoring systems, including slope stability radars and hydrogeological sensors, should be integrated into design frameworks to reduce operational uncertainties. Additionally, future research must focus on sustainability-driven approaches by incorporating carbon footprint, energy consumption, and community impacts into pit planning. Developing unified guidelines that link geotechnical, environmental, and economic criteria will also help in creating safer and more sustainable mine designs.

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