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Investigation of The Mine Design of BBP Mine in Angwan Kade, Kokona Local Government Area, Nasarawa State, Nigeria

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Abstract
The study investigated the mine design of the BBP mine located in Angwan Kade, Kokona Local Government Area of Nasarawa State, Nigeria. The absence of a comprehensive understanding of mining engineering principles in the initial planning phase of the mine necessitated a thorough investigation to identify and rectify the shortcomings in the existing mine design. The research focused on determining the nature and strength of the parent rock, effective mine design, and suggest appropriate support systems. Comprehensive geo-mechanical analyses were conducted using Uniaxial Compressive Strength (UCS) tests and Schmidt Hammer tests. Fieldwork and laboratory tests revealed that the rock mass, predominantly gneiss, exhibits structural integrity ranging from weak to strong, with UCS values between 24.77 MPa and 57.93 MPa, and Schmidt Hammer from 63 MPa to 70 MPa. The findings indicate that the rock varies from moderate to strong, necessitating support systems for underground mining operations in the mine. The heterogeneity in rock strength highlights the need for tailored mine design and support strategies based on local geological conditions. Recommended support systems include the application of shotcrete to provide additional surface support, particularly in areas with fractured rock, and the use of timber frames in less competent sections to maintain structural integrity. The study emphasizes the importance of integrating detailed geological mapping and continuous monitoring to adapt the mine design to changing conditions within the vertical shaft. The findings also provide a robust foundation for safe, efficient, and cost-effective mining operations, ensuring the sustainability of the mining project in the BBP mine.

Keywords: *BBP mine, mine design, support system, rock strength.*

1.0 Introduction

The process of removing valuable ores and minerals from the earth is called mining. These ores and minerals are transformed into the metals or alloys that society needs in a variety of forms. All resources, including those needed for human consumption and construction, originate from mining. The population is growing at a quicker rate than supply, hence demand is rising daily. Recycling is not a full answer; it will only provide a small percentage of the need since there is excess demand for minerals and metals. Nowadays, mining is essential to practically every aspect of our life. Additionally, mining creates a large number of jobs and boosts the economy considerably (Saliu and Idowu, 2014; Idowu *et al*., 2021).

A subfield of engineering known as "mine planning" aims to organize mine operating decisions and economic assessment by taking into account many factors such as market pricing, costs, and details about the ore deposit to be mined as well as plant procedures (Sturgul, 2000). It attempts to provide answers to queries like: how much is the deposit worth economically, how can the mines' development be temporarily halted, which resources should be allocated, etc. Over the past 30 years, mine design has developed significantly and is now on its own a recognized field within mining engineering (Ren *et al.,* 2018). Mine design is a complex process that involves planning, scheduling, and optimization to ensure safe and efficient extraction of minerals (Taiwo *et al*., 2023). Recent advances in technology and computational methods have significantly improved the field, enabling more accurate and data-driven decision-making (Afum and Ben-Awuah, 2021).

For stope boundary optimization, researchers have explored various methods to define the most profitable and safe boundaries for mining, considering like ore factors grade, rock stability, and ventilation requirements. Additionally, studies have applied mathematical programming and simulation techniques to optimize short-term and long-term production schedules (Afum and Ben-Awuah, 2021). In maximizing efficiency and minimizing costs, some computational methods have been embraced such as, Monte Carlo Simulations, Discrete Event Simulation and Pathfinding Algorithms (Skawina *et al.*, 2022). The Monte Carlo analytic hierarchy (MAHP) has been used to evaluate access and transportation routes for underground mines, considering technical, economic, and social-environmental factors (Cardozo *et al.*, 2023; Aladejare *et al.*, 2024).

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The accuracy and suitability of the mine design have a major impact on the productivity and efficacy of a mining operation. Geology, engineering, and environmental concerns are just a few of the many factors that go into mine design in order to maximize resource extraction while maintaining sustainability and safety (Smith, 2012). Research has also explored the application of cemented rock fill (CRF) in cut-and-fill stoping operations, demonstrating its potential to improve stope stability and ground stability (Idowu and Benedict, 2024).

A mine design plan includes elements like topographic profile, geological interpretation, mine layout, pit design or bench slope model and scheduling.

A variety of factors are taken into account in the engineering parts of mine design, including but not limited to ventilation systems, equipment selection and infrastructure development. Furthermore, a thorough examination of the engineering design can highlight areas where innovation and technical developments can improve mining output while lessening its negative effects on the environment (Velykorusova, 2023).

As workable methods for designing mines were discovered, attention was primarily drawn to three (3) categories of issues, namely:

i. Maximizing profitability for the allocated investment cost by optimizing basic design parameters for new and reconstructed mines.
ii. Identifying the best investment schemes for the development of economically valuable mineral deposits and scheduling the related design and investment work.
iii. Support system to ensure maximum safety and avoid health hazards that pose dangers to mine workers.

A geological interpretation of mine sites is of great interest and it should be included in the area of Mine Design Plan (Lin, 2010). This interpretation is based on surveys. The identified major problems present formidable obstacles that require in-depth analysis and strategic solutions to ensure the successful and responsible extraction of valuable minerals. The key issues include:

1. ***Rock Strength Variability***

The varying strength of the rock formations within the BBP Mine poses a substantial challenge to the mine design. Inconsistent rock strength can impact drilling, blasting, and excavation processes, leading to inefficiencies and potential safety hazards (Hoek and Brown, 1980; Aidan, 2019; Rehman *et al*., 2018). Understanding the spatial distribution and characteristics of rock strength variations is essential for developing tailored mining methods and support systems to address these challenges (Zhu *et al.,* 2020).

2. ***Inadequate Geological Expertise in Mine Planning***

The mine plan at BBP Mine was formulated by a geologist lacking specialized expertise in mine design. This inadequacy has resulted in suboptimal mine layouts, inefficient extraction methods, and an increased likelihood of encountering geological challenges during operations. The absence of a comprehensive understanding of mining engineering principles in the initial planning phase necessitates a thorough investigation to identify and rectify shortcomings in the existing mine design.

3. ***Significant Distance between Overburden and Ore***

The considerable distance between the overburden and ore deposits at BBP Mine poses a high stripping ratio and may adversely impact operational efficiency. Addressing this issue requires a detailed examination of the mine design to optimize the spatial arrangement of overburden and ore, reducing cost complexities and enhancing overall productivity.

The presence of fractured rocks in the shafts of BBP Mine necessitates the implementation of a robust support system to ensure the safety of workers and the stability of underground structures. The absence of an effective support system may lead to structural failures, compromising the integrity of the mine and posing serious risks to personnel. Investigating and designing appropriate support systems tailored to the geological conditions is imperative for mitigating these risks (Hoek and Brown, 1980; Delgado and McCleskey, 2008). The two basic parts of ground support strategies are support and reinforcement.

The application of a support load at the excavation surface using surface support materials like shotcrete and mesh is referred to as support. Installing support components within the rock mass, such as rock bolts and cable bolts in boreholes, is the goal of reinforcement, which tries to strengthen the overall qualities of the rock mass. In order to stabilize the excavations, surface support components and reinforcements are applied, which is known as a ground support system (Kang, 2014). To fully understand the requirements of support systems in vertical shafts in underground mining, it is essential to analyze the various factors that affect their design and maintenance (Yang *et al.,* 2023). Vertical shafts in underground mining have specific requirements that need to be considered in the design and maintenance of support systems.

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In light of these challenges, a comprehensive investigation into the mine design of BBP Mine in Angwan Kade becomes imperative. The study aims to address these problems systematically, proposing solutions that enhance the efficiency, safety, and sustainability of mining operations at the site. The outcomes of this investigation will not only contribute to the improvement of the BBP Mine design but also serve as a valuable reference for future mining projects facing similar geological and engineering complexities.

1.1 Description of the study area

The study area for this project work is at Angwan Kade in Kokona Local Government Area (LGA) of Nasarawa State, Nigeria. Angwan Kade, is a small village, rich in lithium mineral deposits and substantially enriching Nigeria's natural resources and mineral wealth. Angwan Kade is underlain by the Nigerian basement complex, a geological formation consisting of ancient rocks such as gneisses, schists, and granites. The study area is also characterized by metasedimentary rocks, including quartzites and phyllites which have undergone metamorphism due to tectonic activity. The study area is known for its mineral deposits, including gold, tin, lithium, and tantalite, which are found in the quartz veins and pegmatites.

It shares borders with the Federal Capital Territory (FCT) to the west and is surrounded by other LGAs within Nasarawa State. The area is situated in a hilly region, with elevations of 262 meters above the sea level. Angwan Kade experiences a tropical savanna climate, with distinct wet and dry seasons. The area is covered by savanna grasslands and woodlands, with scattered trees and shrubs. The local communities are primarily engaged in subsistence farming, mining, and trading.

Figure 1 shows the study area, which is located in the central part of Nasarawa State with Coordinates of N 8° 51' 20" and E 8° 3' 40". The economy of Kokona LGA is primarily agrarian. Farming activities, including the cultivation of crops and livestock, form the backbone of the local economy. The region's fertile soil supports the growth of various crops, contributing to the agricultural productivity of the area.

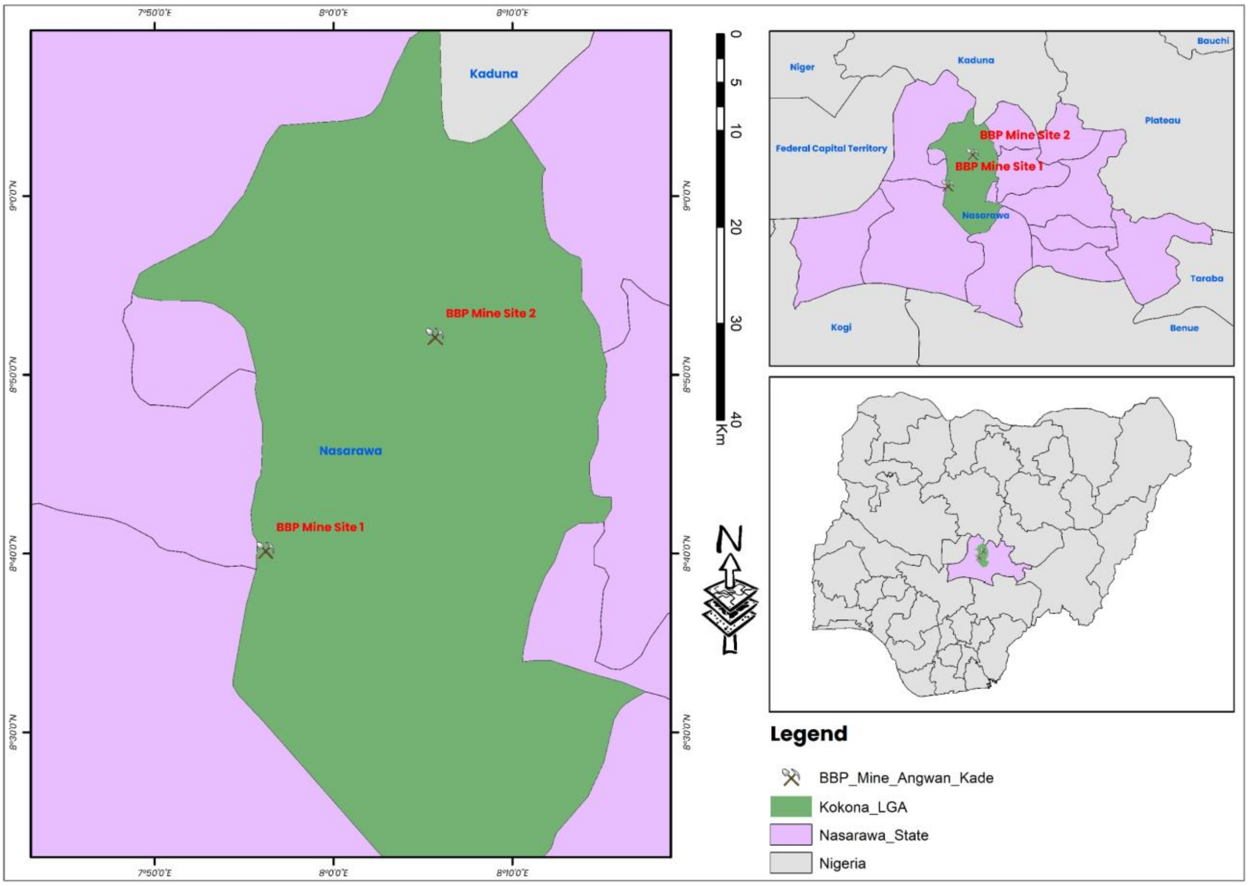

Figure 1: Map showing the study area

This study area provides a unique opportunity to understand the geology and socio-economic characteristics of the region with significant mineral deposits and artisanal mining activities.

2.0 Materials and Methods

The study reviewed existing research on mine design, planning, and optimization was exhaustively conducted to identify the key factors, challenges, and global best practices. The research also employed the use of CONTROLS – 1000 kN S12V02 Uniaxial Testing Machine to measure the compressive strength of the rock samples. This high-capacity machine applied uniaxial pressure to the rock samples until they failed, providing accurate data on their strength. For the direct Uniaxial Compressive Strength (UCS) test, rock samples were prepared in accordance with International Society of Rock Mechanics (ISRM) standard of cylindrical shape with a diameter of approximately 50 mm and length to diameter ratio of 2.5:1. This ratio is critical for ensuring that the test results accurately reflect the rock's strength under uniaxial stress conditions (ISRM, 1999). The data obtained from this machine was crucial in evaluating the mechanical properties of the rock and informed decisions related to the mine's structural integrity.

The Schmidt Hammer was another essential tool used in the study, specifically for measuring the surface hardness of the rock samples. This non-destructive tool provided a quick and reliable estimate of the rock's strength and elasticity by measuring the rebound of a spring-loaded mass impacting the rock surface. The hardness values obtained from the Schmidt Hammer were used to assess the uniformity of the rock material and to cross-verify the results from the UCS test. This tool was particularly useful in preliminary assessments and in situations where a quick evaluation of the rock's surface properties was needed.

Automatic computer-aided design (AutoCAD**)** software was employed to create detailed drawings and designs for the mine shaft and support systems. The software allowed for precise visualization of the project's structural elements, facilitating the creation of accurate and scalable designs. AutoCAD's advanced features enabled the integration of various design parameters, ensuring that the final plans were comprehensive and aligned with the research's goals. The use of AutoCAD was instrumental in planning and executing the mine's design phase (support systems), contributing to the overall success and accuracy of the study.

3.0 Results and Discussion

The UCS tests were performed on rock core samples from different depths in the vertical shaft. Table 1 shows the UCS values for each sample and Figure 2 represents the uniaxial compressive strength graphically.

Table 1: UCS test results

S/N	Sample	Cross-Sectional Area (Mm^2)	Volume (Mm^3)	Weight (G)	Breaking Load (KN)	Uniaxial Compressive Strength (MPa)
1	A1	2376.14	594196.43	165.45	60.14	25.31
	A2	2376.14	594196.43	149.03	57.58	24.23
	Average	**2376.14**	**594196.43**	**157.24**	**58.86**	**24.77**
2	B1	2376.14	594196.43	157.08	93.17	39.21
	B2	2376.14	594196.43	154.80	73.12	30.77
	Average	**2376.14**	**594196.43**	**155.94**	**83.15**	**34.99**
3	C1	2376.14	594196.43	154.90	64.80	27.27
	C2	2376.14	594196.43	156.84	76.50	32.20
	Average	**2376.14**	**594196.43**	**157.60**	**70.65**	**29.73**
4	DI	2376.14	594196.43	163.33	142.37	59.92
	D2	2376.14	594196.43	166.58	132.90	55.93
	Average	**2376.14**	**594196.43**	**164.96**	**137.64**	**57.93**

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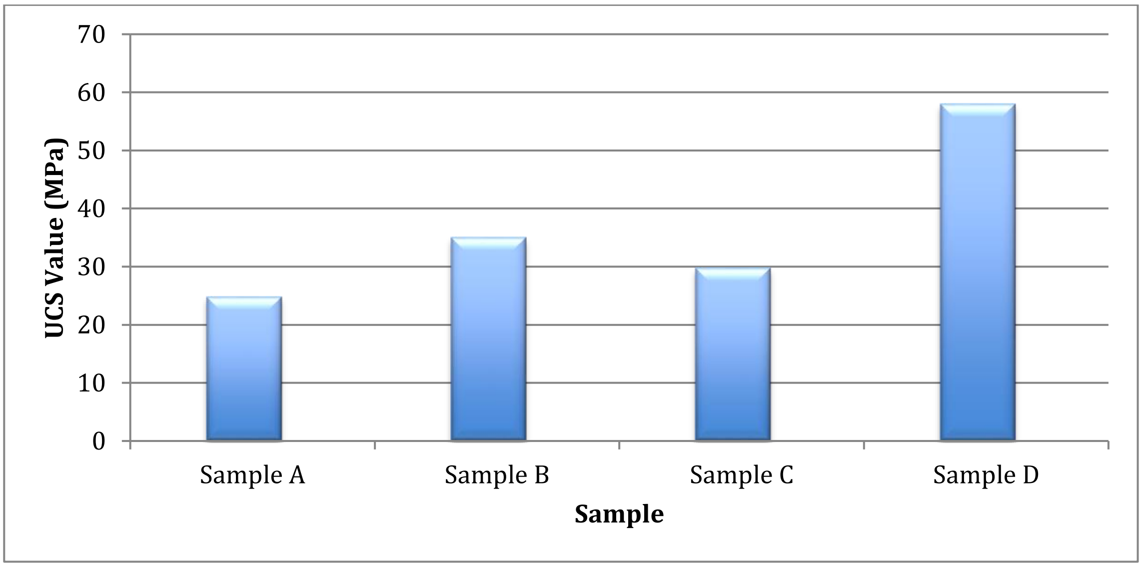

Figure 2: Graphical representation of direct UCS result using the average

3.1 The uniaxial compressive strength

Variations in UCS values suggest heterogeneity in the rock mass, likely due to differences in mineral composition and existing geological structures. From the UCS test results, the rock samples exhibit varying degrees of strength. Analyzing the results with the standard rock strength from Table 2.

Table 2: Gneiss UCS values and grades (ISRM, 1999)

UCS value (MPa)	Grade	Remark
<50	Low	Weak and not ideal for mining
50 - 100	Medium	Moderate Strength
100 - 200	High	Strong, Suitable for mining
>200	Very high	Very strong, Highly Suitable

The UCS values obtained from the direct tests on gneiss rock samples range from 24.77 MPa to 57.93 MPa. These values are significantly lower than the typical UCS range for gneiss rock in underground mining, which is between 50 MPa and 200 MPa. This indicates that the samples tested may not be ideal for use in high-stress mining operations due to their lower strength. However, one sample (Sample 4) does meet the minimum standard with a UCS value of 57.93 MPa, placing it in the medium strength category.

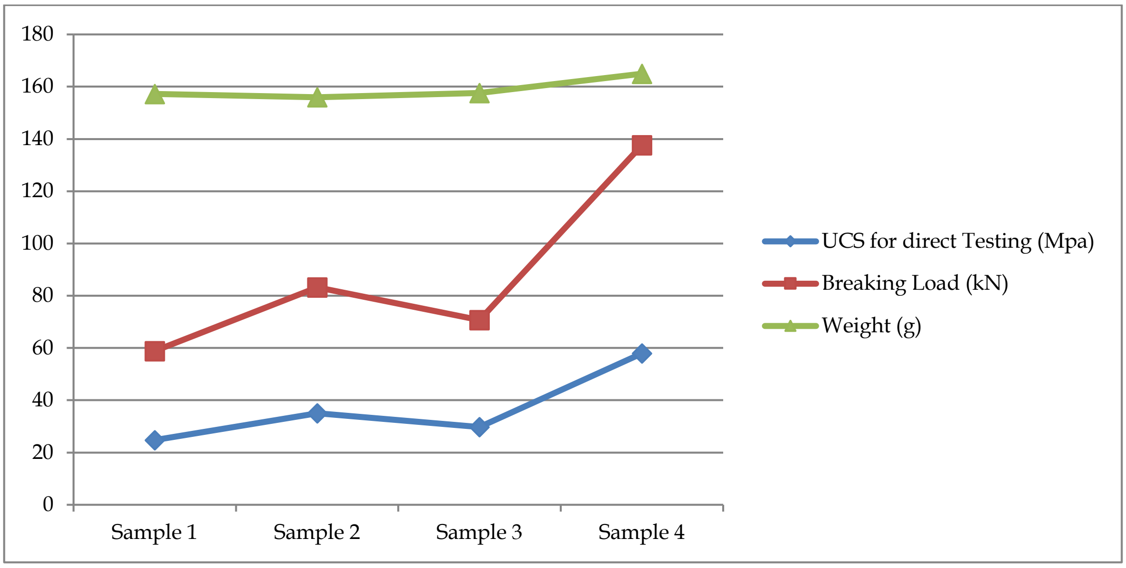

Figure 3: Graphical representation of the effect of breaking load on UCS value

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Figure 3 shows that there's a positive relationship between the breaking load, weight and direct UCS value. As the breaking load and weight increases, the UCS value also increases indicating that samples capable of withstanding higher loads and having larger weights generally exhibit higher compressive strength.

3.2 Schmidt Hammer Test

The Schmidt Hammer test was conducted to measure the rebound values, which correlate to the hardness and strength of the rock samples. Table 3 and Figure 4 represent the Schmidt Hammer results for seven gneiss rock samples and the graphical representation respectively.

Table 3: Schmidt Hammer Test Results

Sample ID	Rebound Value 1	Rebound Value 2	Rebound Value 3	Average Rebound Value	Compressive Strength from Rebound Graph
Sample 1	60	58	46	54.6	70 $\pm$7
Sample 2	49	52	52	51.0	65
Sample 3	56	45	50	50.3	63
Sample 4	54	55	57	55.3	70 $\pm$7
Sample 5	51	53	53	52.3	67
Sample 6	49	52	50	50.3	63
Sample 7	51	50	54	51.6	65.5

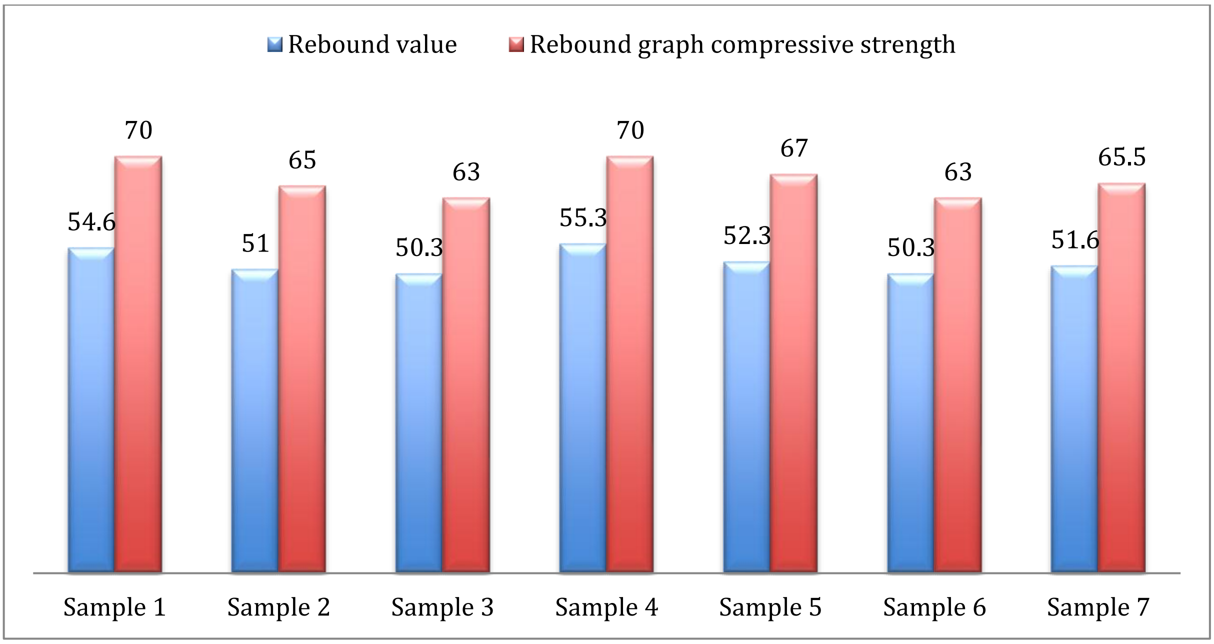

Figure 4: Graphical representation of rebound value to graph compressive strength

3.2.1 Unconfined Compressive Strength Analysis based on Rebound Empirical Correlation

Using the empirical correlation from the Schmidt Hammer test, the compressive strength of the rock is calculated using Equation 1 below.

$$UCS = 0.43XR \tag{1}$$

Table 4 shows the calculated UCS values based on the rebound values and its graphical representation can be found in Figure 5.

Table 4: Unconfined Compressive strength analysis based on Rebound Empirical Correlation

Sample ID	UCS 1 (MPa)	UCS 2 (MPa)	UCS 3 (MPa)	Average UCS (MPa)
Sample 1	25.8	24.94	19.78	23.51
Sample 2	21.07	22.36	22.36	21.93
Sample 3	24.08	19.35	21.5	21.6
Sample 4	23.22	23.65	24.51	23.78
Sample 5	21.93	22.79	22.79	22.50
Sample 6	21.07	22.36	21.5	21.64
Sample 7	21.93	21.5	23.22	22.21

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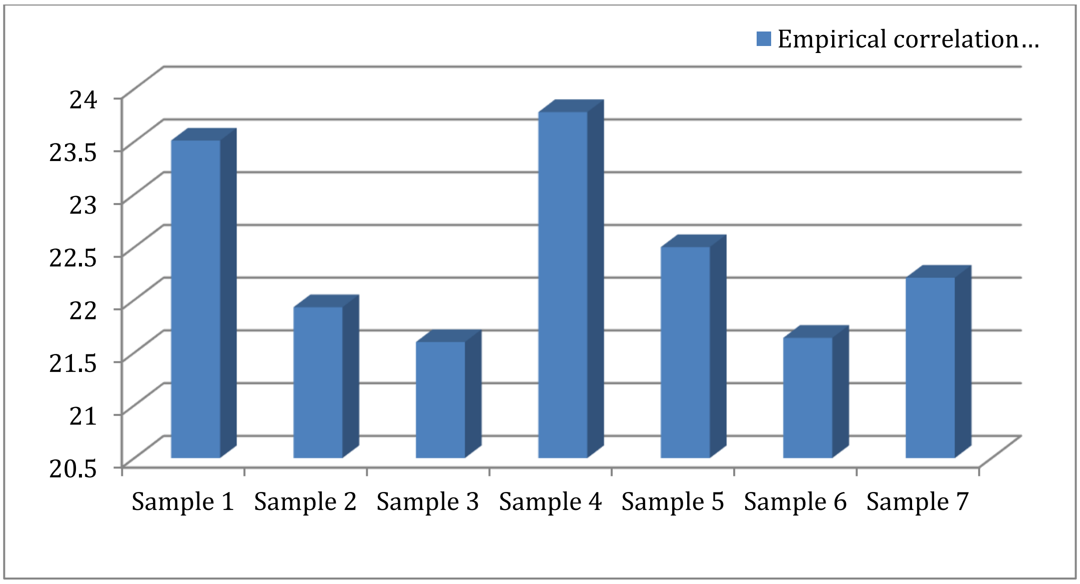

Figure 5: Graphical representation of unconfined compressive strength analysis based on Rebound Empirical Correlation

The Schmidt Hammer test results indicate that the compressive strength of the rock samples ranges from 63 MPa to 70 MPa, classifying the rock as strong.

The UCS values derived from the empirical correlation generally align with the direct UCS test results, confirming the reliability of both testing methods.

The results from both UCS and Schmidt Hammer tests indicate that the rock in the vertical shaft varies. The highest UCS values are observed in deeper sections of the shaft (D1 and D2), indicating a potential increase in rock strength with depth.

3.2.2 Empirical Correlation UCS Values

The empirical UCS values, derived from correlations based on other rock properties, consistently show lower strength values than the direct UCS tests. The empirical UCS values range from 21.6 MPa to 23.78 MPa which is close to the values for the direct UCS testing method.

However, this discrepancy suggests that the empirical method may underestimate the actual strength of the gneiss samples. This could be due to various factors, such as the empirical correlation not being fully calibrated for the specific characteristics of the gneiss rock in this study.

3.3 Strength of the rock

The UCS values ranging from 24.77 MPa to 57.93 MPa suggest that the rock needs support due to significant loads expected as in general underground mining operations and the empirical correlation from Schmidt Hammer results further support the classification, and needs further reinforcement as corroborated by Yang *et. al*., (2023) and Aladejare *et al*., (2024).

The comprehensive analysis of UCS and Schmidt Hammer test results indicates that the rock in the vertical shaft is moderately strong, which can pose significant problems across various underground mining methods and will need recommended support systems and mining practices to ensure stability, safety, and cost-effectiveness in mining operations.

3.4 Support system design

With the low to medium rock strength exhibited by the parent rock, support system should be of paramount importance to ensure safety (Nam *et al*., 2002; Pouyan, 2019). The two-support system recommended are i) Timber support as main support and ii) Shotcrete as initial support as shown in Figures 6 (a-d).

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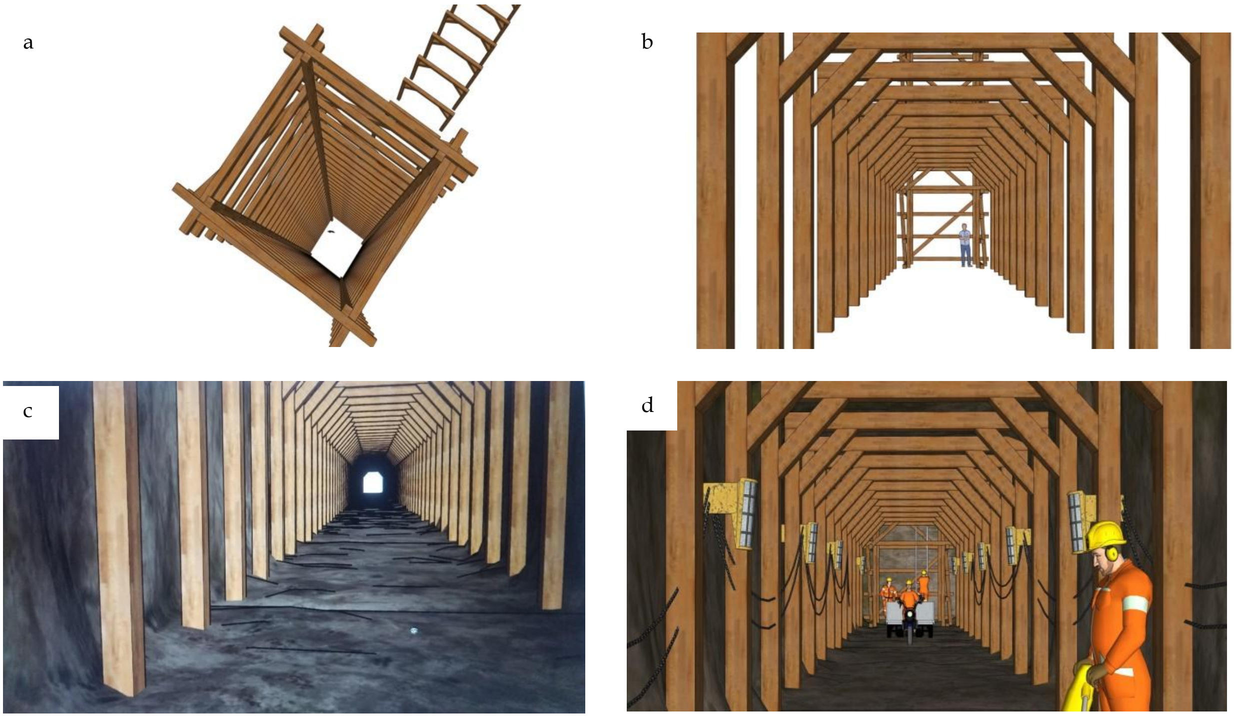

Figures 6 (a-d): Support system showing shotcrete and timber support systems

4.0 Conclusion and Recommendation

4.1 Conclusion

The investigation into the rock strength and nature within the vertical shaft of BBP mine at Angwan Kade, Kokona in Nasarawa State, Nigeria revealed that the gneiss rock samples exhibit varying degrees of strength, ranging from moderately strong to strong. The Uniaxial Compressive Strength (UCS) values ranged from 24.77 MPa to 57.93 MPa, indicating that while some samples fall within the medium strength category, others are below the typical UCS range for underground mining. These findings highlight the necessity of careful consideration of local geological conditions to optimize mine design and safety. The study provides a solid foundation for developing effective mining strategies tailored to the specific conditions of the site. Overall, the investigation offers valuable insights into the geo-mechanical properties of the rock mass and presents practical recommendations for support systems and drilling techniques, contributing to the successful exploitation of the BBP mine.

4.1 Recommendation

The findings recommend that regular maintenance and inspections of support systems to minimize cost and prevent constant repairs. Also, proper installation and maintenance of support systems are very crucial for preventing accidents and reducing downtime as recommended in Figures 6 (a – d). However, the workforce also needs to be well-trained in all the basic and general safety protocols.

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