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A Practical Modeling Approach using Room and Pillar Mining Method for the Exploitation of Ankpa Coal Deposit

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ABSTRACT

The aim of this research is to design underground workings using a room and pillar mining method for the extraction of Ankpa coal deposit in Nigeria. Representative samples for each lithologic unit were collected from the Ankpa coal mine formation and laboratory testwas carried out to determine their geotechnical properties. These tests were carried out in accordance to ISRM suggested methods, and were used as input parameters to describe each geomaterial in the RS3 finite element geotechnical software. The Rocscience RS3 three-dimensional numerical design tool was used to correctly model the coal formation, design the excavation and to analyze the stability of the excavation. The underground working was developed in four stages, and the result for maximum effective principal stress and total displacement was computed. The maximum effective principal stress value of 5295.71 kPa was attained. The stress was concentrated at the middle of the developed mine panel, while the overall total displacement is 0.019 m. The model shows a promising design with good stability if it is lightly supported at the center of the stope.

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1. INTRODUCTION

Large scale extraction of coal officially began in Nigeria in 1916, at Ogbete mine in Enugu State. (Nigeria Coal Corporation, 1982). The success achieved led to coal exploration and production in other areas of the country including Ankpa in Kogi State, Owukpa in Benue State and Lafia/ Obi in Nassarrawa State (Odesola et al., 2013). Coal exploitation and use was indeed a major driver of the nation's economy at that time. Coal production increased rapidly from its inception to a peak value of 920,000 tons per year in 1959. This however did not last long as it suffered a major decline from 1959 to 1966 with an annual production of 220,000 tons (Ogunsola, 1991). This was majorly because of the discovery of oil and gas in 1956. Railway locomotives were replaced with oil driven engines, the nation began to depend on hydro-power for electricity generation and the country major export speedily shifted concentration to oil and gas (Odesola et al., 2013;

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Baiyewu, 2015). During the civil war in 1967, the production of coal was terminated (Sambo, 2008). Nevertheless, coal has certainly not lost its relevance. Studies have been made into harnessing coal for power generation, and it is still being used as a major energy source for industrial operations (Elijah, 2014). For example, the cement industries in Nigeria still use coal to power their plants for cement mixing. This justifies the need to resuscitate the production of coal in Nigeria, bringing into full production the existing small-scale coal mine in Nigeria and reawakening the abandoned mines.

Ankpa coal mine which became operational in 2011 is one of such coal mine still operating at a very small scale using the surface open cast method. The mine has a total reserve of 380 million metric tons (Baiyewu, 2015). Commercial coal mining resurfaced again in Nigeria at Ankpa when mining license was issued to ETA Zuma Group by the Federal Government of Nigeria (Baiyewu, 2015). Zuma (2011) explained that the geology of Ankpa coal mine is such that a larger portion of the coal reserve will remain inaccessible through open cast mines because of the high stripping ratio and that it is only through a combination of surface and highwall mining that the coal reserve in the area can be completely extracted. This indicates that although, an open cast mining method is currently being practiced in Ankpa coal mine, an underground mining method will still have to be developed to assess the major portion of the coal deposit because of the high stripping ratio that will render the technique uneconomic as mining progress deeper. This technique of mining underground deposits is proposed by driving tunnels underneath the surface of the current open cast mine. This is a viable method as it has been used in time past under diverse geologic conditions to increase the recovery of coal seam (Shimada et al., 2013; Luo, 2014; Mo et al., 2016). Tzalamarias et al. (2019) noted that the success of this scheme is depended on the stability of the working conditions of the underground mining district and the productivity planned to be achieved by the mining technique.

It is pertinent to design a suitable underground mine workings that can recover a major portion of the coal seam, promoting the use of mechanized equipment as well as maintaining a stable overall mine structure during and after mining to avoid surface subsidence. Wagner (1980) suggested that traditional room and pillar mining technique can be adopted to mine coal deposit ranging in depth from 50 to 150 m with a coal seams thickness ranging from 1 to 4 m. This is also supported by the fact that room and pillar mining methods leave pillars in place to maintain overall mine structural stability and disallow surface subsidence (Hartman, 1992). The aim of this research is to design suitable underground room and pillar working at the Ankpa coal mine using RS3 finite element geotechnical software, and to evaluate the stability of the excavation from the values of the maximum stress and total displacement.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The Ankpa coal mine is located in Kogi State, north central part of Nigeria, approximately 150 kilometers north of the city of Enugu and 80 kilometers west of the city of Makurdi and is located by grid reference on latitude 07°20°14°N and longitude 07°30°31°E. Figure 1 shows the location of the study area. The coal seam thickness ranges from 2 to 3 m and averaging 2.5 m. The main coal seam appears to be continuous from Ogboyoga and is projected to extend throughout the Ankpa area. The coal maintains a mineable thickness over all of the property and good mining conditions for mining along the outcrop. Ankpa coal mine dominant lithology includes laterite, shale and coal seam. Figure 2 shows the field view of the three different lithology of the deposit, laterite layer, shale layer and coal seam. The laterite soil layer forming the overburden at Ankpa mine has a thickness of 20 m. The soil layer is followed by shale layer with a thickness of 40 m. Beneath the shale lies the coal seam of average thickness of 2.5 m and is currently being exploited using surface mining method. The shale formation also forms the footwall of the coal deposit.

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Figure 2: A field view of the lithology of Ankpa open pit mine

2.2. Properties of the Coal Formation

The modeling of the coal formation was necessitated by the need to correctly estimate the geotechnical and geomechanical properties of the overlying materials and that of the coal in accordance to suggestions by ISRM (2010). This was carried out on representative samples obtained from the field and these properties values were subsequently used as inputs for the modeling of the coal formation, assuming an elasto-plastic deformation using the Mohr-Coulomb failure criterion. The properties determined were the bulk density, uniaxial compressive strength, cohesion (C) and frictional angle (Φ), the deformation parameters (elastic modulus and Poisson ratio). Five (5) samples of each lithological unit were collected at 5 meters apart and the tests were carried out on the representative samples of each lithological unit. The bulk density was estimated using Equation 1 as suggested by ISRM (2010).

$$\rho = \frac{M}{V} \tag{1}$$

Where ρ = Bulk density (g/cm³), M= Bulk mass of the sample (g) and V= Bulk volume of the sample (cm³) The procedure stated by ISRM (2010) for the determination of uniaxial compressive strength in the laboratory was adopted using Equation 2.

$$UCS = \frac{P}{A} = \frac{4P}{\pi D^2} \tag{2}$$

Where UCS= Uniaxial compressive strength (Pa), P= Maximum axial load at failure (N), A= Cross- sectional area (m^2) and D= Average diameter of sample (m)

The Young's modulus and Poisson's ratio were estimated from the results of uniaxial compression tests suggested by ISRM (2010). Load and axial and circumferential strains or deformations was recorded at a constant rate of axial deformation. The axial and diametric strain were calculated as shown in Equations 3 and 4.

$$Ea = \frac{\Delta l}{l} \tag{3}$$

Where Ea = Axial strain, l = original measured axial length and $\Delta l =$ change in measured axial length (defined to be positive for a decrease in length)

$$Ed = \frac{\Delta d}{d} \tag{4}$$

Where Ed= Diametric strain, d = original undeformed diameter of the specimen and Δd = change in diameter (defined to be negative for an increase in diameter)

The stress values for each interval were plotted against their corresponding axial and diametric strains to give a curve showing the typical behavior of rock materials from zero stress up to ultimate strength. The Axial Young's modulus was determined from the average slopes of the more-or-less straight-line portion of the axial stress-axial strain curve. Poisson's ratio, V, was calculated from Equation 5.

$$V = -\frac{\text{slope of axial stress-strain curve}}{\text{slope of diametric stress- strain curve}}$$
(5)

The triaxial compression test was conducted according to the methods prescribed by ISRM (2010).

The values of the internal friction $angle(\emptyset)$, and the apparent cohesion(C) were calculated using Equations 6 and 7.

$$\emptyset = \arcsin\frac{m-1}{m+1} \tag{6}$$

$$C = b \frac{1 - \sin\theta}{2\cos\theta} \tag{7}$$

Where m and b are the slope and the intercept of the straight line defining the strength envelope respectively.

2.3. Numerical Modeling

The thickness of each lithologic unit as obtained from the face and the average physical and mechanical properties obtained from the laboratory experiments was used as input parameters for the numerical modeling and analysis. The rock units were modeled as different geomaterials with their respective geotechnical properties, assuming elasto-plastic deformation using the Mohr–Coulomb failure criterion. The underground working was developed in four stages and the maximum effective principal stress and total displacement analysis were computed for each stage. The coal formation was discretized and meshed accordingly using a 6-nodded triangle, uniform mesh type and an approximate number of mesh element of 1500 were selected for the purpose of this study as shown in Figure 3. The numerical model began from the topsoil layer to a depth of 72.5 m, a lateral width of 240 m and a horizontal extent of 120 m. This allowed the top layer of the model free to move in the X-Y direction while the lower parts being fixed to the ground. The gravity loading was used to account for the increasing overburden stresses and hydrostatic initial stress state was assumed for the numerical model.

The numerical model was developed in four stages to capture the changes in the stress regime and overall displacement as more excavations were made. The first stage accounts for the pre-mining condition and the in-situ stress state. The second stages consist of the development of the two main entry tunnels and a crosscut to link the tunnels. The third stage sees the completion of the developed room and pillar mine of the first

panel while the fourth stage completes the room excavations of the two mine panels. Figures 4 and 5 shows the complete view of the second and third stage while Figure 6 shows the 3D view of the complete mine model.



Figure 3: Coal formation model showing the different lithologic units, discretization and meshing

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Figure 4: Numerical model at the second stage of the developed mine



Figure 5: 3D view of the complete mine model



Figure 6: Numerical model at the third stage of the developed mine

3. RESULTS AND DISCUSSION

The average results of the estimated geomechanical properties for each lithologic unit as obtained from the laboratory is presented in Table 1. The laterite topsoil has an average density of 1.94 g/cm³ indicating a high compaction and consolidation ability as pointed by Bolarinwa et al. (2017). The table shows that laterite and shale layer have moderate to low density which poses a low overburden pressure on the coal seam and enhances stability (Okeke and Okogbue, 2011). The Shale layer has an average density of 2.16 g/cm³ and a UCS value of 3.2 MPa which is in close range with corresponding values obtained by Okeke and Okogbue (2011) and Anikoh and Olaleye (2013). The coal formation lithology has low UCS values, and falls in the lowest category of the Uniaxial Compressive Strength classification by Bell (1992). The lithology however has moderate shear strength parameters; the shale has a cohesion of 208 kPa and an internal frictional angle of 31.6°, which makes it a fairly competent hanging wall of the coal measure, and promises stability if it is adequately supported. The shear strength parameters of the shale are within the same range of the roof of similar underground workings by Saharan *et al.* (2012) and Tzalamarias *et al.* (2019). The coal has cohesion and frictional angle value of 231.7kPa and 27.6° and it is well considered in the design of the pillar geometry to ensure sufficient stability.

Table 1: Geomechanical properties of the overlying materials and that of the coal			
Lithology/properties	Laterite	Shale	Coal
Density (g/cm ³)	1.94	2.16	1.07
UCS (Mpa)	0.24	3.2	1.24
Young's modulus (GPa)	0.11	1.2	0.52
Poisson's ratio	0.32	0.3	0.27
Cohesion (KPa)	50.2	208	231.7
Frictional angle (°)	32.7	31.6	27.6

The maximum effective principal stresses contour plots for the four stages are shown in Figure 7 to Figure 11. It was observed that the *in-situ* stress increased gradually with depth from 48.49 kPa to a maximum value of 1437.09 kPa at stage I. Stage II records a maximum stress value of 3011.40 kPa principally concentrated at the middle of the excavated entry tunnel. The principal stress contour at stage III shows a steep increase and is mainly concentrated at the mid-section of the developed mine panel reaching a value of 5234.16 kPa. The principal stresses of the excavated mine at stage III is shown in Figure 10. The maximum principal stress value of 5295.71kPa was attained at stage IV, concentrated at the middle of the developed mine panel and is clearly shown in the expanded view of the excavated stress contour in Figure 11.



Figure 7: The maximum effective principal stress for the external surface at stage I



Figure 8: The maximum effective principal stress for the external surface at stage II



Figure 9: The maximum effective principal stress for the external surface at stage III



Figure 10: The maximum effective principal stress for the excavated mine panel at stage III



Figure 11: The maximum effective principal stress for the excavated mine panel at stage IV

The total displacement at stage I was approximately zero, as there was no excavation made yet and hence no distortion in the uniform stress field of the numerical model. The maximum displacement of the numerical model at stage II was 0.0079 m and it occurs along the mid line of the entry tunnel. The excavation contour at stage III shows a maximum total displacement of 0.019 m and this occurs at the center of the excavated mine panel while the non-excavated mine panel has a maximum displacement of 0.013 m occurring along the mid-section of the main entry tunnel. Ultimately, the highest total displacement of 0.019 m was reached at stage IV, occurring at the center of each excavated mine panel, while the displacement along the entry tunnel at this stage is 0.016 m. The total displacement of the excavated mine panel is shown in Figures 12 and 13 respectively.



Figure 12: The total displacement contour of the excavated volume at stage III

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Figure 13: The total displacement contour of the excavated volume at stage IV

4. CONCLUSION

The underground room and pillar coal mine panel was adequately designed after establishing the lithology of the coal formation and the determination of the average thickness of each geologic layer from the top surface to the layer directly beneath the coal seam. The geomechanical properties of the different lithologic unit were determined in the laboratory, the values of which were used as inputs in the numerical model. The coal mine panel, the pillar, the entry tunnel and the excavated rooms were designed in their respective geometry sizes and shapes. The implementation of the developed mine model is very feasible as the maximum values of the contour plots poses no major threat to the stability of the mine structure. The development of additional coal mine panels in the room and pillar mine will result in a very gentle gradient in the maximum values of the field condition. The most critical section of the numerical model occurs at the centre of the developed mine panel. It will require a suitable support system to ensure stability.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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