

Geotechnical Application for the Design and Estimation of Amata-Lekwesi, Nigeria Open Mine

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Abstract
The need for a proper understanding of the subsurface geology of a place and the depositional pattern of what is to be mined is very important in establishing its mining trend especially if such deposits are not exposed at the surface. Eleven borings were made in the quarry pit and around the surrounding berm to depths of 25 meters at a sampling interval of 1.0m into the intrusive rock bodies using Slanzi rotary diamond coring rig. The depth range of the boreholes varies from 15.0 meters to 25.0 meters. Rock/Soil samples obtained from borings were subjected to both visual field examination and laboratory tests/analyses to guide in designing a mine system that is based on the geology, trending pattern and geotechnical properties of the rocks. The intrusive was observed to trend in the east-west orientation. However, north-south trends were also observed at certain sections of the mine/quarry. The values of the plunges of the intrusive were observed to be between 2^o and 6^o at the northern southern segments. The average thickness of the intrusive bodies varies from 11.20m for the surrounding bench area to 20.00m in the pit. This observed thickness of rock mass covers an area of approximately 81,750 m^2, made up of 29,500 m^2 for the floor of the quarry and 52,250 m^2 for the surrounding bench. The area of the surrounding berm and the pit floor area are 52,250 m^2 and 29,500m^2 respectively. A total reserve tonnage of 3,874,000 was obtained.
Keywords: Geotechnical, Mining design, intrusive body, Slanzi rotary diamond coring rig, Quarry, Trend, Plunge

1. Introduction
The importance of systemic approach to mine planning and design using soundly based geotechnical engineering methods cannot be overemphasized .The coherent variability of naturally occurring materials is an important aspect that need to be recognized and allowed for a geotechnical engineering (Zuniga et al, 2007; Beacher and Christian 2003; Hebblewhie, 2009; Marshall, 2011).

There are also a number of significant challenges in geotechnical engineering that have not yet been fully resolved in strict scientific sense. Furthermore, there is no single solution in the geotechnical design and operation at any given mine (Hudson et al. 2003, Brandy and Brown, 2007; Beck and Sundy, 2002). These are important points to understand particularly because of the variability in the ground conditions and the mining methods in use.

Geotechnical issues must be systematically considered during the whole life of a mining operation from its beginning in the pre-feasibility study stage through the operation of the mine to the final closure and abandonment of the mine (Alogoz (2007)). Geotechnical data for design can be obtained from a number of sources including published literature, natural outcrops, existing surface and underground excavations, chip and diamond drilling, geophysical interpolating seismic records, pump taste, field tests, trial pits, and express (Mines Occupational Safety and Health Advisory Board, 1999). However, such data can be used to identify areas requiring more detailed investigation and analysis.

It is recognized that open pit mining experience and professing judgment are important aspects of geotechnical engineering that are not easily quantified, but can contribute significantly to the foundation of various acceptable and equally viable solutions to a particular mining problem (Zuniga et al 2007). Management at each mining operation should recognize identity and address the geotechnical issues that are unique to each particular mine, using convenient geotechnical knowledge.

The potentially hazardous nature of open pit mining requires the application of sound geotechnical engineering practice to mine design and general operating procedures to allow safe and economic mining at any commodity within any rock mass (Bowden, 2004; Brazil et al, 2004; Hebbebite, 2003). The design of open pit excavations will endeavour to prevent hazardous and unexpected failures of the rock was during the operating life of the open pit.

Open pit mines can represent a complex engineering system with many sub-systems that need to function in an integrated manner for the mine to operate safely and economically. Mine planning deals with the correct selection and coordinated operation of all the systems. The systems include mine production capacity, workforce numbers, equipment selection, budgeting, scheduling and rehabilitation. Mine design is the appropriate engineering design of all the sub-system on the overall mine structure of production and near-wall blasting, loading and haulage platforms, electric powers water control dust control ground support and reinforcement, and excavation geometry (Alogoz, 2007, Bach at al, 2004). It is recognized that during the geological design stage there is usually limited detail of the overall rock mass available and that it is necessary to make a number of a assumptions/simplifications to arrive at a balanced mine design (Xu et al, 2011; Aroncibia et al, 2008; Andrienx et al 2010).

Regional tectonic, insitu stresses and other geological variable control the stress field in the rock surrounding a mine opening. Knowledge of the magnitudes and directions of these insitu and induced stresses is an essential component of underground excavation design. Large sets of field measurements can be analyzed and insitu stress sensor can be estimated for underground mine design (Anderson et al 2009; Gumede and Stacey 2007).

A well managed ground control plan is a necessary component on any successful mining project. A ground control management plan would include pre-mining investigations of ground conditions, development of a mine plan and design according to the assessed ground conditions and required rates of prediction etc (Mines Occupational Safety and Health Advisory Board, 1999). Once mining is underway a system of ground performance monitoring and re-assessment of more designs should be under taken such that the safe operation of open pits can be mentioned for the duration of mining.

Few local quarries owned by the natives are found scattered within Amata-Lekwesi, Nigeria All these quarries adopted the open-pit method of mining, which is always froth with uncertainties because of the subsurface nature of the igneous intrusive in some parts of the area. The need for a proper understanding of the subsurface geology therefore becomes very important to establish the mining trend of any of the quarry deposits that are not exposed at the surface. Thus, the research was conducted out of the need to save one of such industries from absolute abandonment due to exhaustion of mineable rocks.

1.1 Study Area

Amata-Lekwesi (fig.1), is located approximately on latitude 5^0 55′ and longitude 7^0 40′.The area falls within the southern part of the 6000km long belt of the Cretaceous sediment of the Benue Trough (Olade, 1976). The land use is mainly farming and few improperly exploited open-pit mines by the natives and the Crush Stone quarry.

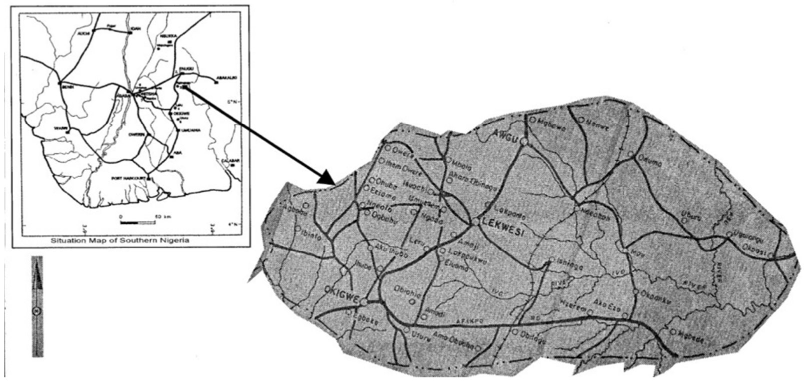

Figure 1: Location Map of the Study Area

1.2 Regional Geologic Setting

By early Albian, these transcurrent movements had initiated a series of isolated depositional centres and sub-basins where mostly alluvial fans, braided stream and lacustrine sediments constituted the initial deposits prior to extensive marine incursions. The onset of the earliest eustatic transgressive episode in the mid Albian gave rise to marine sedimentation of the Asu River Group within the Benue Trough. The 2000 meter thick sequence of shales and siltstones with minor pyroclastics belonging to the Albian Asu River Group form the underlying rocks in the southern portion of the aulacogen (figure 2). These rocks grade northwards into shallow marine platform carbonates of the middle Benue (Arufu and Gboko formations) (Reyment, 1965).

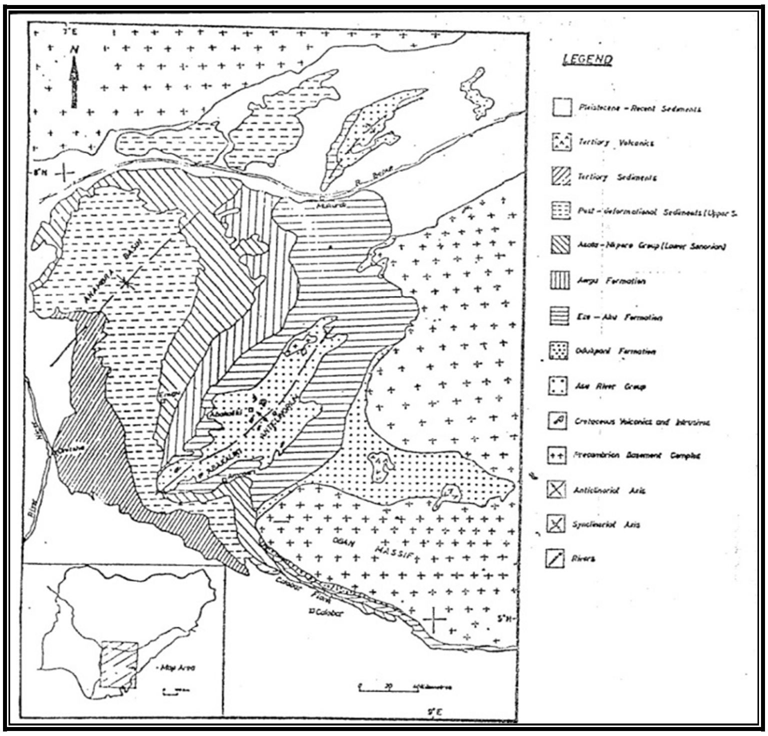

Figure 2: General Geology of Southern Portion of the Benue Trough (after Nigerian Geological Survey, 1984)

The intrusive dykes resulting from the magmatism are located at various depths, having Eze-Aku shales at the base and the Awgu shales at the top of the intrusive (table 1) and the Mid Senonian lower coal measures overlying the Nkporo shales. Some of these intrusive which appear domal in shape (like those at the Crush Stone Quarry site at Isiagu) are found close to the surface and yet deeper at some parts. The depth variation and domal nature may suggest various levels of magmatic sill structures (Wright, 1968; Murat, 1972).

Table 1: Stratigraphy of the Study Area

AGE	GROUP/FORMATION	LITHOLOGY
Cretaceous (Mid Senonian)	Lower coal measures	Coal, Sandstone, Shales
Cretaceous (Lower Senonian)	Nkporo Shale Group	Shales, Mudstone
Santonian-Early Campanian	Awgu Shale	Shales and Siltstones
Cretaceous	Intrusives	Intrusives (Quarry rock)
Cretaceous (Turonian)	Eze-Aku Shale Group	Blach Shales, Siltstones
Cretaceous (Albian to Mid Cenomenian)	Asu River Group	Shales, Limestones

2.0 Materials and Methods

Data for the work was generated through geotechnical subsurface investigation (using Slanzi rotary diamond coring rig) for the purposes of establishing the trend and geotechnical characteristics of the intrusive body, depth of overburden rocks, estimate of the reserves of mineable rock bodies and the overall plan of the quarry site. A total of eleven (11) borings were made to depths of 25 meters into the intrusive rock bodies (Fig.3). Drilling is carried out both in the quarry pit (BH6, BH7, BH8) and around the surrounding berm (BH1, BH2, BH3, BH4, BH5, BH9, BH10, BH11). A sampling interval of 1.0 meter was maintained for the cored rock samples from each of the eleven drilled holes. Rock/soil samples obtained from borings were subjected to both visual field examination and laboratory tests/analyses to guide in designing a mine system that is based on the geology and geotechnical properties of the rocks.

3.0 Results and Discussion

3.1 Litho-Stratigraphy

The litho-Stratigraphy of the area is as shown in figure 3. The range of depth of the overburden materials is between 0.00 meter in the quarry pit (BH6, BH7, BH8) to 20.00 meters on the berm (BH9). The overburden materials are mainly shale (light greyish shale, yellow greyish shale, dark greyish and black shale) and lateritic clayey sand. Borehole (BH9), located about 50.00 meters west of BH8 touched the intrusive from 20.00 meter depth. This perhaps indicated a westward dipping trend for the rock.

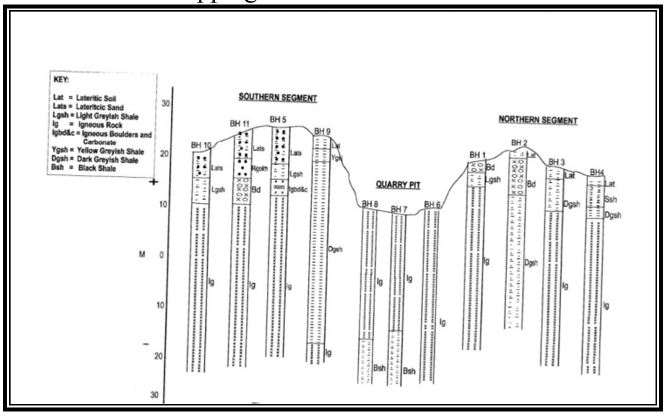

Figure 3: Litho-Stratigraphy of the Study Area

A thickness of 6.5 meters of highly fractured boulders was discovered in BH2, located 35.00 meters east of BH1. Below these boulders was the dark grey shale down to a depth of 25.00 meters. The absence of any fresh rock body from this borehole down to the final depth of drill (25.00m) could indicate that the intrusive dyke-like structure never extended beyond the region of BH2. However, apart from BH2, a general trending pattern is seen running from the northern segment (BH1, BH3, BH4) through the quarry pit (BH6, BH7, BH8) to the southern segment (BH10, BH11).

3.2 Orientation of the Intrusive Body

The intrusive was observed to trend in the East-West orientation. However, North-South trends were also observed at certain sections of the mine/quarry. The values of the plunges of the intrusive were observed to be between 2.00^o and 6.00^o at the northern segment and 4.00^o to 6.00^o at the southern segment. The outline of the observed rock outcrop distribution in and around the quarry is as shown in figure 4. Cross sections AA', BB', CC', DD' and EE' (Figs 5a & 5b) indicate the subsurface orientation of the rocky outcrops within the mine area.

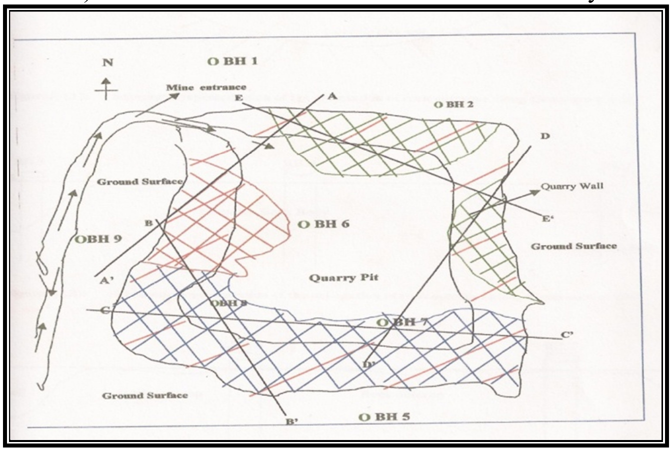

Figure 4: Schematic Representations of the Distribution and Orientation of Rock Outcrops at the Amata-Lekwesi Quarry

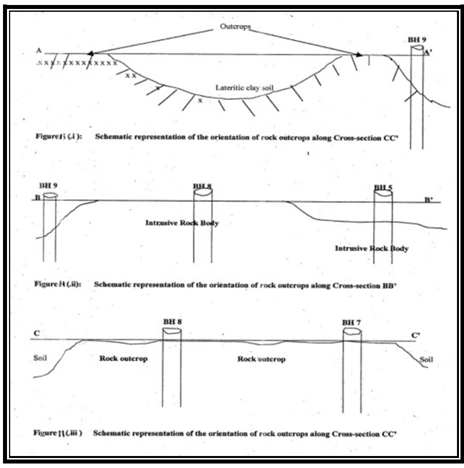

Figure 5a: Cross Sections AA, BB and CC

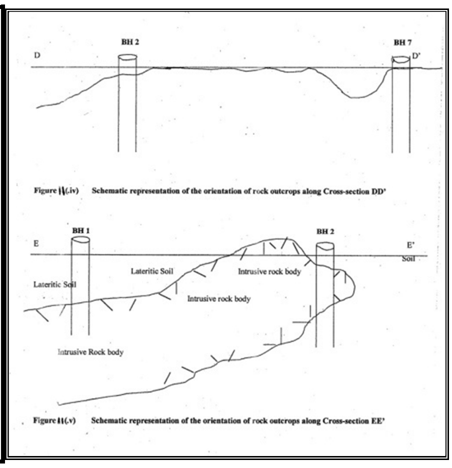

Figure 5b: Cross Sections DD and EE

3.3 Thickness of Intrusive Body

The average thickness of the intrusive bodies varies from 11.20 meters for the surrounding bench area to 20.00 meters in the pit. This observed thickness of rock mass covers an area of approximately 81,750 m^2, made up of 29,500 m^2 the floor of the quarry and 52,250 m^2 for the surrounding bench (table 2).

Table 2: Estimates of the Intrusive Rock Bodies

PARAMETERS	INTRUSIVE ROCK BODIES										
	BH1	BH2	BH3	BH4	BH9	BH5	BH10	BH11	BH6	BH7	BH8
Depth to top of intrusive rock body (m)	5.9	0.40	5.85	11.60	21.00	7.50	4.50	5.00	0.00	0.00	0.00
Depth to bottom of intrusive rock body (m)	>00.12	7.40	19.85	23.60	>25.00	22.50	>23.50	18.00	23.00	23.00	13.50
Thickness of rock body (m)	>00.51	7.00	14.00	12.00	>4.00	15.00	>19.00	13.00	23.00	23.00	13.50
Average rock thickness (m)	11.20					16.00			20.00		
Area of intrusive rock body (m^2)	37,350					15,000			29,500		
Volume of intrusive rock body (m^3)	417,200					240,000			590,000		
Reserve (tonnes)	Volume of Rock x Density of Material = 1,722,400 x 2.98 = 5,132,752										

3.4 Rock Volume Computation and Life Expectancy of the Mine

The estimated area between the three (3) borings located within the quarry pit (BH6, BH7 and BH8) was approximately 29,500m^2. Using an average rock thickness of 20.00m between these borings, a rock volume of 590,000m^3 is obtained and with a rock density of 2.98 mg/m^3 a unit tonnage of 1,758,200 tonnes for the quarry pit is computed. The estimated area of the surrounding berm is approximately 52, 250 m^2 while that of the pit floor is 29,500m^2 thus, the total area of 81,250 m^2 is obtained. With an average thickness of 16.00m, the rock volume is 1,300,000 m^3.The rocks has a density of 2.98 mg/m^3 thus, a total reserve tonnage obtained is 3,874,000.

3.5 Life Expectancy

The life expectancy of a mine or quarry is usually determine by the reserves of the mineable rock materials. The reserves are usually divided by the agreed production quantities per year by the mine operators. Assuming the agreed production quantity of the quarry by the operators is x tonnes per year, when the proven reserves of the mine is y tonnes, then, the Life Expectancy of the mine are given as:

$$LE = y/x \text{ (in years)} \quad \text{..........................eq (1)}$$

If a total of ten trailer loads, each of 30,000 tonnes of crushed stone are mined per day for a total of six days per week over a period of one year, this will translate into 86,400 tonnes per year. Based on the above equation, the life expectancy (LE) of the mine is 44.8 years. It should be noted however, that the life expectancy

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of any given mine during the mining operations depends on several factors.

(a) Unplanned changes in the annual production quantities for the mine due to unforeseen reasons such as sudden increase in crushed rock demands.
(b) Short-fall in the availability of rock materials due to lack of investigation to determine the reserves proper orientation.
(c) Failures of operational equipment due to unanticipated breakdowns or lack of replacement of spare parts for effective repair of machines.
(d) Industrial unrest occasioned either by workers' dissatisfaction with conditions of service or grievances occasioned by company policies or other reasons.

3.6 Mine Systems Design

The mine systems design proposed for the study area takes into consideration the mine plan, adequate haulage way, mine slope angle (θ), mine wall height (h), excavation plan and mine drainage.

3.6.1 Mine Plan

The existing mine plan shown in Figure 6 indicates that the major (long) axis is trending north-south with the mine expansion in the north-south direction. However, it was observed from subsurface investigations that the rock bodies are trending in the east-west direction and so the mining should progress in the same direction as the rock trend, which plunges at a value of about 35-40 degree westwards. The mine plan as existing and modified respectively at the study area is shown in figures 6.

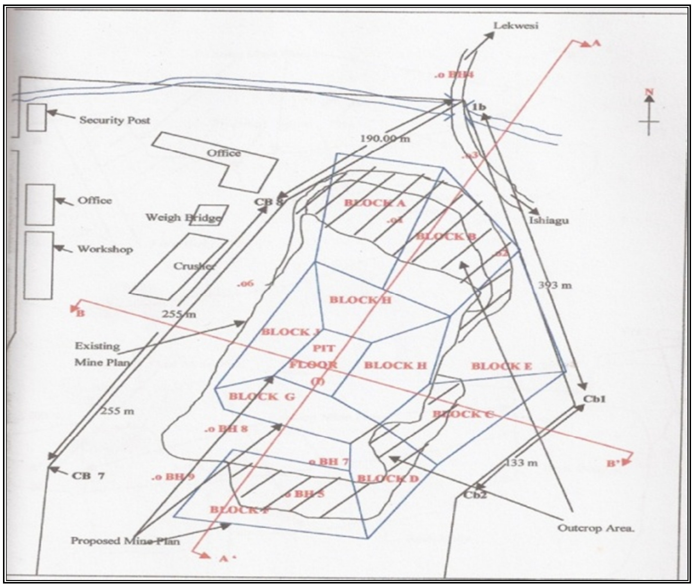

Figure 6: Existing and Proposed Schematic Mine Plan for Crush Stone Quarry at Amata-Lekwesi

3.6.2 Mine Haulage Way

The main haulage way for the site is situated along the western segment of the mine layout commencing from the crusher plant and trending north-eastwards along the western edge of the mine to a point where it enters the mine close to the northern edge of the mine (figures 7).

In constructing the haulage ways, attempts should be made to have slopes not steeper than the traction friction angles (θ) of the tyres of the mine vehicles. A haulage way slope angle of about 20-25 degree is recommended.

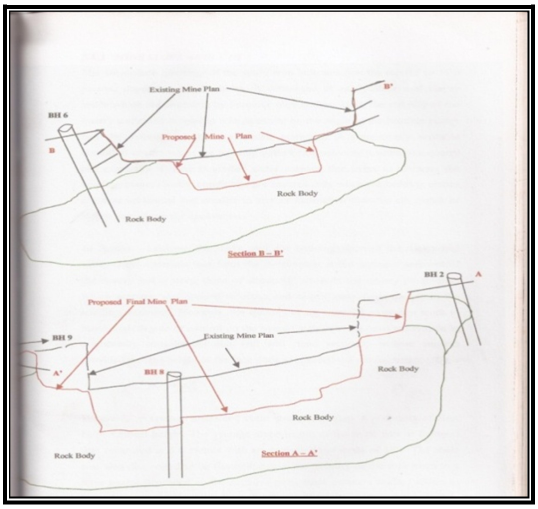

Figure 7: Cross Sections of Existing and Proposed Mine Outlines at Amata-Lekwesi Quarry

3.6.3 Mine Slope Angle

The subsurface lithology of the study area indicates that the top 0.5 to 11.0 metres, depending on the holes, is composed of sandy shale and clayey sands which are underlain by intrusive rock bodies. Thus, the stability of the quarry walls will depend to a large extent on the angle of the bedding planes and the stability of the overburden materials. A dangerously unstable condition occurs when the bedding planes slope steeply towards the quarry pit, especially if there is groundwater seepage that helps to lubricate the bedding planes. Stable conditions are assured only when the bedding planes are near horizontal and smaller in size or inclination than the cut slopes or slopes away from the excavation.

The shaley and sandy shale materials that form the overburden at the northern segment of the quarry has a steep slope of about 48^0 towards the quarry pit through which seepage was noticed to occur and slopes away from the pit in the southern segment. However, the stability of the material properties tends to insert high degree of control on the overall stability. An open excavation in a normally consolidated clay soil will stand vertically without support provided that the height of the face does not exceed the critical height ***(Hc).***

$$Hc = \frac{4Cu}{\gamma} \quad \text{................................ eq. (2)}$$

where c_u = average untrained shear strength of clay, γ = density of clay, Hc = critical height. The average slope length of the mine face was measured at 5.0 metres with an average slope angle of 58^0. The shale was also discovered to be fissured; hence the stability of the rock mass to a large extent depended on the negative pore-water pressure in the fissures to keep the mass tightly stable in the undisturbed situation.

On removal of this lateral pressure by excavation, a positive pore-pressure is initiated causing some slide of mass fragments along the mine face at places where the 58^0 slope angle was exceeded. The frictional angle (θ) values of sandy shales and clayey sands can be taken to be approximately 48^0-$50^{0.}$ However, based on the heterogeneity of the materials, a steeper slope than those stated here can be adopted. A recommended slope angle (θ) of 50^0 and 60^0 will be adequate based on actual field trials.

The subsurface lithology at the southern segment indicates that the top 5.0 to about 5.6 metres are composed of lateritic sands and medium to coarse grained sands derived from the in-situ regoliths, below which are the intrusive. Thus, the stability of the quarry walls will depend to a large extent on the stability of the overburden materials. The frictional angle (θ) values of lateritic sands and medium to coarse grained sands can be taken approximately between 40^0 and 46^0. However, based on the heterogeneity of the materials, a steeper slope than those stated here can be adopted. So a recommended slope angle (θ) of between 50^0 and 60^0 will be adequate based on the frictional properties of the field materials.

3.6.4 Mine Wall Height

The wall height of a mine or quarry is controlled principally by the position, direction, orientation and volume of the ore body or the mine-able rock as well as the dimensions of the working equipments in the particular mine. The results of field borings revealed that the maximum depth of the rock body at the northern segment is in excess of 23.0 metres below ground level. This depth is more than a normal mine wall value, thus, it will be necessary to have a bench in-between the two expected lifting levels of rock extraction at the quarry. For the southern segment, the maximum depth is in excess of 21.0 metres below the ground surface. This depth again is more than a normal mine wall height, thus, a bench in-between two expected lifting levels of rock extraction will be required for the trenching of the quarry.

Conclusion

The need for a proper understanding of the subsurface geology of a place and the depositional pattern of what is to be mined is very important in establishing its mining trend especially if such deposits are not exposed at the surface. The potentially hazardous nature of open pit mining requires the application of sound geotechnical engineering practice to mine design and general operating procedures to allow safe and economic mining at any commodity within any rock mass.

Open pit mines can present a complex engineering system with many sub-systems that need to function in an integrated manner for the more to operate safely and economically. Thus, knowledge of the magnitudes and directions of in-situ and induced stresses is an essential component of underground excavation design. A well-managed ground control plan is a necessary component on any successful mining project.

The importance of systemic approach to mine planning and design using soundly based geotechnical engineering methods cannot be overemphasized. There are a number of significant challenges in geotechnical engineering that have not yet been fully resolved in strict scientific sense. However, there is no single solution in the geotechnical design and operation at any given mine. Management at each mining operation should recognize identity and address the geotechnical issues that are unique to each particular mine, using convenient geotechnical knowledge.

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