Summary of Modelling Safety Factors of Slope Stability in A Tar-Sand Quarry: A Case Study

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ABSTRACT— *This research studies the importance of slope stability during open-pit mining of tar sand within the Dahomey basin, Southwest Nigeria. It involved the geotechnical characterization of the layers of Laterites and Alluvium which it underlies. In addition, SLOPE/W software of the GeoStudio package was utilized for deducing and modeling the bench face angles which had higher safety factors, through the Morgenstern Price method of slices. It was discovered that the lateritic soil layer possessed higher values of unit weight, cohesion and internal frictional angle than those of the Alluvial Sand layer. Factors of safety were generated for bench face angles ranging from 10o to 90o at 1m, 4m and above 40m groundwater levels; over a 10m bench width and 6m bench height. However, for heavy equipment, a bench width of 20m and height of 6m were assumed. This resulted in factors of safety varying between 3.58 and 1.73 for bench face angles between 10o and 30o during higher precipitation (and water tables). Thus, this suggests that stable slopes predominate at bench face angles of 10o to 30o. This can be further enhanced when sufficient drainage systems are constructed.*

Keywords— Dahomey Basin, Geotechnical Characterization, Open-Pit Mining, Tar Sand

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1. INTRODUCTION

The study area, Loda Village, Ondo state (Fig. 1) is located on longitude 4°55'E and latitude 6°45'N [13] within the Dahomey basin of Southwestern Nigeria (Fig.2) which extends through South-eastern Ghana, Togo, Republic of Benin and Southwestern Nigeria [7]. Tar sand occurs at the eastern parts of the Dahomey basin within the Upper Cretaceous sediments [1, 2, 12, 11 and 10]. Ref. [6] and [4] believe the East-West trending tar sand outcrop is about 120km long and 6km wide while [3], [5] and [8] estimates the slope angles during its mining at 30º to 35º without laboratory analyses, therefore, creating a need for an accurate determination of the geotechnical properties that influence bench face angles employed during slope design. The study is aimed at accurately estimating bench face angles that are stable and safe during mining by geotechnical characterization of the sediments overlying tar sand deposit using a case study within the Southwestern Nigeria. [9] propose safety factors of 1.2 to 1.4 for rock slopes in open-pit mines and higher for soil slopes while [14] explains that more than 40% of slope failures result from unfavourable groundwater conditions.
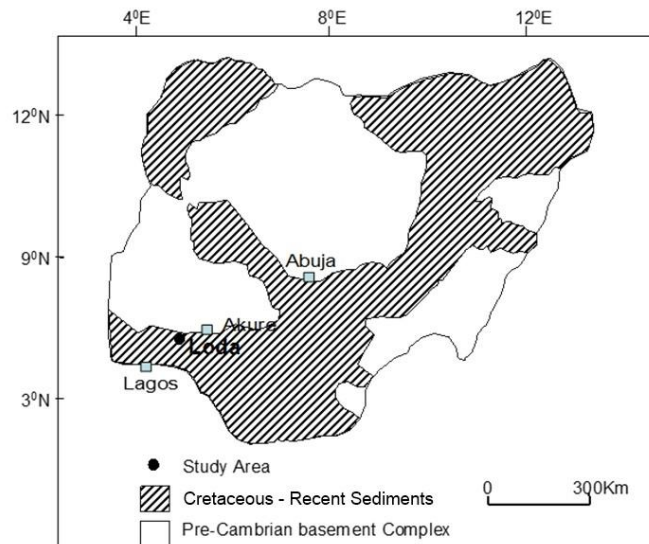
"**Figure 1:** Map of Nigeria showing the study area, Loda Village, Ondo State Southwestern, Nigeria (modified from Kogbe, 1989)."
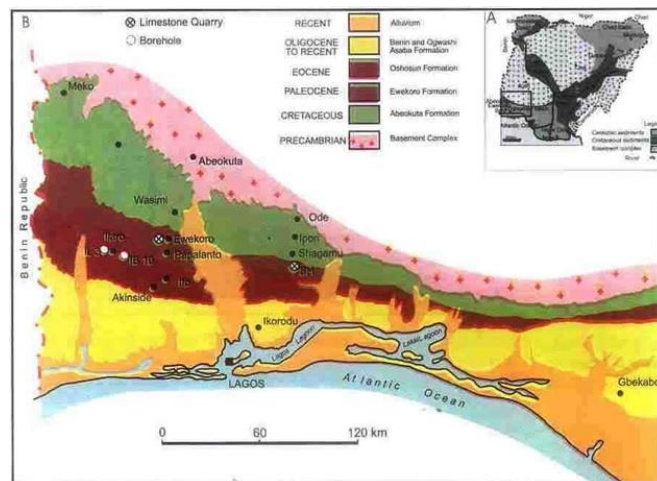

"**Figure 2:** Map showing part of Nigeria and the study area, Loda Village within the Dahomey Basin (Adapted from Bankole et al., 2006)"

2. METHODOLOGY

Primary data were collected from samples taken 200m apart at three locations (L1, L2 and L3) during field mapping along with core drill data obtained from Bitumen Project Implementation Committee (National Agency) and were analysed with results modelled using GeoStudio SLOPE/W software. These samples were collected from the basal parts to the topmost part of the road cut at each location. Graphic sections depicting the lithologies encountered during the mapping are shown in Figures 3a to 3c.
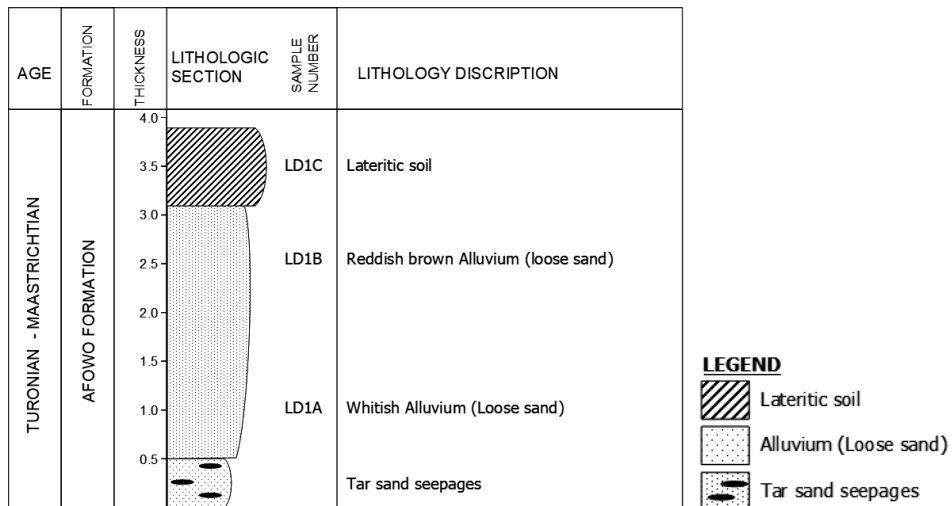
"**Figure 3a:** Lithologic section of road cut examined at Location 1 (LD 1), Loda Village, Ondo state, Southwestern Nigeria"
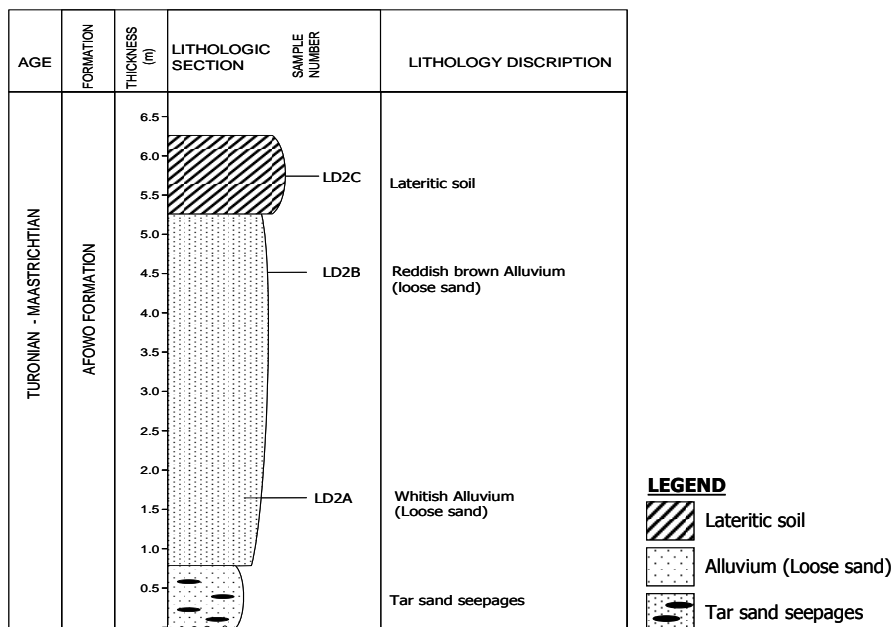
"**Figure 3b:** Lithologic section of road cut examined at Location 2 (LD 2), Loda Village, Ondo state, Southwestern Nigeria."
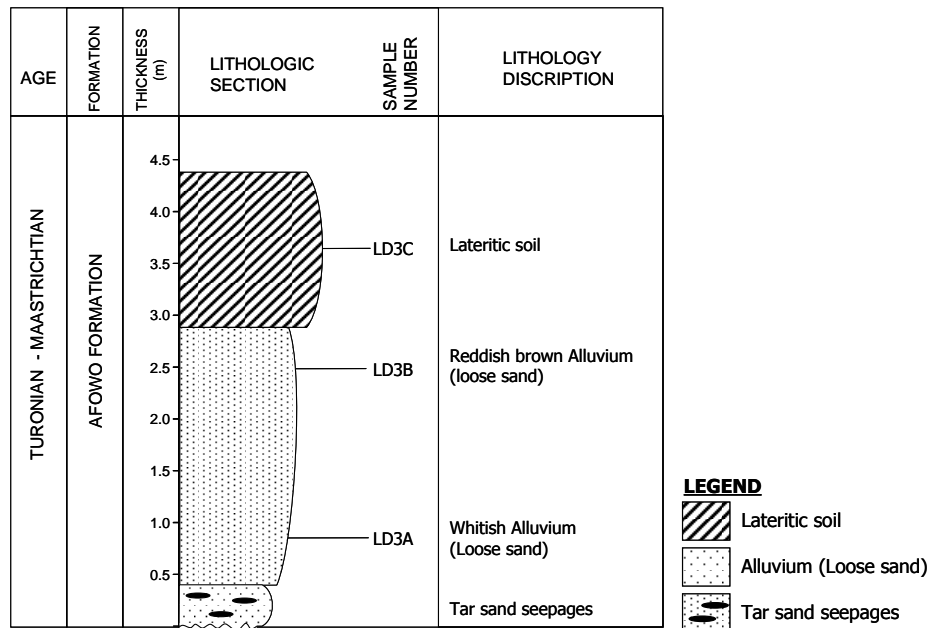
"**Figure 3c:** Lithologic section of road cut examined at Location 3 (LD 3), Loda Village, Ondo state, Southwestern Nigeria"

The geotechnical characterizations included determining the density of each material, using the density bottle; particle size distribution through mechanical dry sieving methods following BS 1377, 1975; and direct shear tests through the use of the 20mm high shear box machine.

During the modeling, hypothetical bench dimension of 10m and 20m with same height of 6m was used while bench face angles were raised from 10° through to 90° in order to calculate the safety factors through the Morgenstern Price method. Furthermore, groundwater levels of 1m (for wet seasons – May to October, with raised water levels), 4m (for dry seasons- November to April) and above 40m were estimated for each bench width attempted and groundwater greatly influences slope stability [14 and 15].

3. RESULTS AND DISCUSSION

The geotechnical parameters analysed and inputted into GeoStudio SLOPE/W (Table I) shows that the topmost layer of Laterites has an higher average unit weight of $25kN/m^3$, mean cohesion of 45kPa and internal frictional angle of 41°. However, the underlying layer of Alluvium which is a cohesion-less, loose sand (average cohesion value = 0) has mean unit weight of $18kN/m^3$ and internal frictional angle of 34° which are lower than that of the lateritic topmost layer.

Table 1: Summary of Geotechnical data inputted into the SLOPE/W computer program for the simulation of Factors of safety.

	Average unit weight values (kN/m³)	Average cohesion values (kPa)	Average angle of internal friction values {In degrees (º)}
Layer 1 – Lateritic Soil	25	45	41
Layer 2 – Alluvium (loose sand)	18	0	34

Figure 4 suggests excavation passes at different bench face angles for open-pit mines at the study area, while Figure 5 models safety factors for various groundwater levels at a slope angle of 40°. Tables 2 and 3 reveal that safety factors are higher for deeper groundwater levels that is, slopes are more stable under such conditions. In addition, following [14 and 9], tables II and III show that bench face angles lower than 30° result in more stable slopes and allow for inundation.
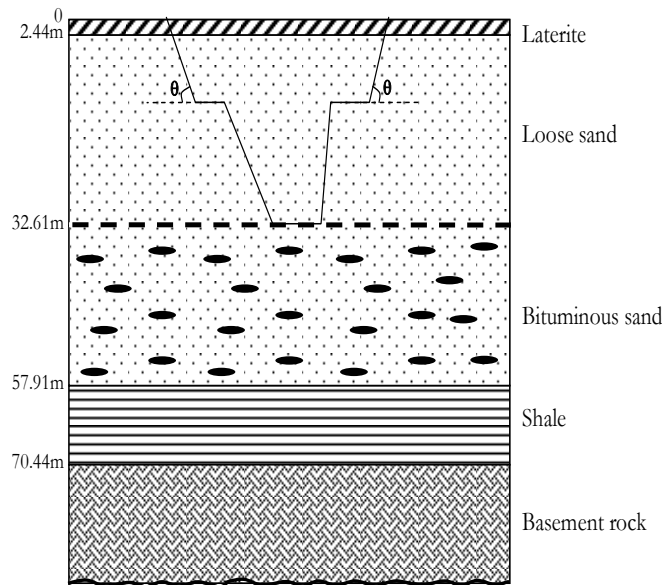
"**Figure 4:** Diagram showing a pass at slope angle determination and how excavation might occur for an open pit mine using Loda Village southwestern Nigeria as a case study."
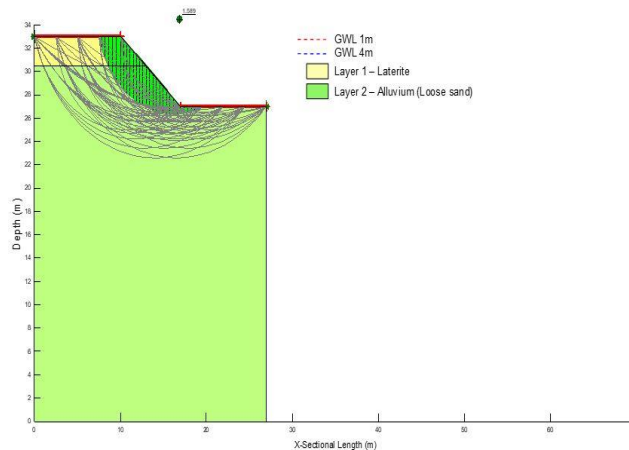
"**Figure 5:** Simulation of 40^0 slope angles to determine the corresponding factors of safety values for different ground water levels using a 10 meters bench and 6 meters bench height. "

Table 2: Table showing the factor of safety values obtained from computer simulation using different slope angles for a bench width of 10 metres and bench height of 6 metres cut into the two layers overlying the tar sand deposit at Loda Village, Southwestern Nigeria.

SLOPE ANGLE (IN DEGREES,°)	MORGENSTERN-PRICE METHOD OF ANALYSIS		
	1m Piezometric level	4m Piezometric level	Very deep Piezometric level (>40 metres)
10	3.37	3.91	4.20
20	2.03	2.26	2.44
30	1.56	1.61	1.82
40	1.35	1.39	1.58
50	1.18	1.37	1.51
60	1.05	1.24	1.35
70	0.79	1.22	1.25
80	0.65	1.07	1.15
90	0.35	1.02	1.09

Table 3: Table showing the factor of safety values obtained from computer simulation using different slope angles for a bench width of 20metres and bench width of 6metres cut into the two layers overlying the tar sand deposit at Loda Village, Southwestern Nigeria.

SLOPE ANGLE (IN DEGREES, °)	MORGENSTERN-PRICE METHOD OF ANALYSIS		
	1m Piezometric level	4m Piezometric level	Very deep Piezometric level (>40 metres)
10	3.58	4.20	4.51
20	2.41	2.66	2.72
30	1.73	1.85	2.16
40	1.66	1.51	1.85
50	1.52	1.30	1.82
60	1.19	1.42	1.59
70	0.96	1.28	1.40
80	0.83	1.18	1.25
90	0.59	1.02	1.09

4. CONCLUSION AND RECOMMENDATION

In order to assess the slope stability of Tar sand deposit at Loda Village, Ondo state, Southwestern Nigeria, geotechnical analyses was carried out on two lithologies overlying the deposit. The values obtained from the geotechnical analyses were used to simulate the bench face angles of a proposed open-pit mine under different groundwater conditions, with slope angles of 10° to 30° being more stable and safer than face angles above 30º.

It is, therefore, recommended that:

- Groundwater pressure should be constantly measured and monitored using appropriate equipment such as piezometers;
- Stability of the slopes should be adequately monitored using state-of-the-art facilities like extensometer (to measure movement) and high-energy pumps (for dewatering);
- Construction of wide trenches and effective drainage systems.
- The use of high-energy submersible pumps for dewatering is necessary when mining commences.

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