

MODELLING SAFETY FACTORS OF SLOPE STABILITY FOR OPEN-PIT MINING OF NIGERIAN TAR-SAND DEPOSITS

D. A. ALAO

**Department of Geology and Mineral Sciences;
University Of Ilorin, P.m.b. 1515, Ilorin, Nigeria
E-mail: dafalao@unilorin.edu.ng**

ABSTRACT

Slope failure might lead to loss of lives and valuable equipment which would increase overall operational cost of running a mine. The need to have stable slopes in open-pit mining of Nigerian tar sand deposits of Dahomey Basin, Southwestern Nigeria is emphasized in this study. At Loda village, Southwestern Nigeria, samples of the laterite soil and alluvial sand which overlie the tar sand occurrence were subjected to geotechnical tests. Computer simulation of bench face angles was carried out using SLOPE/W Software to determine the bench face angle(s) with the least susceptibility to failure.

Unit weight (γ), cohesion (c) and angle of internal friction (ϕ) values for the laterite soil were 25 kN/m, 45 kPa and 41 respectively for laterite. The corresponding values for the alluvial sand were 18 kN/m³, 0kPa and 34°. These values were used to run the software programme to simulate different bench face angles that could be cut into the two lithologic units. Factors of safety values between 3.58 and 1.73 were obtained for bench face angles between 10° and 30° which are least susceptible to failure even when inundation is considered. This research results have enabled us to recommend the use of bench slope angles ranging from 10° and 30° coupled with adequate drainage conditions which should guaranty optimum output.

Keywords: Dahomey Basin, Tar-sand, Bench face angle, slope stability, Open-pit mine and factor of safety.

INTRODUCTION

Dahomey Basin, located in West Africa, runs parallel to the coastal margins of Ghana, Togo, The Republic of Benin and Southwestern Nigeria. It is an extensive basin starting from Southwestern Ghana through Togo and the Republic of Benin, to Southwestern Nigeria where it is separated from the Niger Delta by Okitipupa Ridge.

Tar sand occurrences in the Dahomey Basin are restricted to the eastern portion of the basin and are contained. Tar sand occurrences in the Dahomey Basin are restricted to the eastern portion of the basin and are contained.

Gaps are measured in time and are equal to headways. generally in Upper cretaceous sediments. Extensive bituminous seepages and sediments impregnated

with tarry oil define a narrow band about 5-8 km wide between latitude 6°37'N and 6°48' N stretching from just east of Ijebu-ode town (Ogun State) to the banks of the tributaries of the Siluko river at Ofosu village in Edo State (Nigeria), approximate distance of 110 km (Alao and Kazeem, 2004).

A lot of work has been carried out on reserves estimation (Adegoke et al. 1976), physical and chemical characteristics (Adegoke et al. 1976). Clay mineral suits and exploitation options. One of the new recent works carried out relate to the geotechnics of the Nigerian tar sand (Alao, 2004b).

However, previous work gave an estimate of 30° to 35° for slope angles when mining of the tar sand deposit commences. This was based on approximations and estimations without actually carrying out laboratory tests. Hence, the need for exact determination of the geotechnical parameter (such as shear strength, unit weight and angle of internal friction) necessary for bench face slope design. This paper examines the geotechnical properties of sediments associated with and overlying the tar sand deposit of southwestern Nigeria. This would be related to finding out the bench face angles safe for mining. Field activities included sediment description, identification and collection. Also core drill data were obtained from the Bitument Project Implementation Committee, an arm of the National Agency charged with such responsibilities.

Geotechnical tests were carried out on samples obtained and the results were utilized with the geostudio SLOPE/W software.

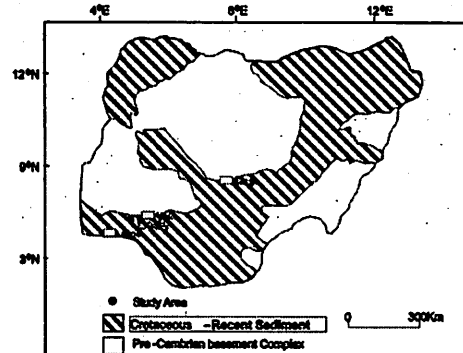


Figure 1: Location of Study Area, Loda Village

2.0 LOCATIONS OF THE STUDY AREA

The study area located on longitude 4°55'N is Loda village, Ondo State, Southwestern Nigeria (Figure 1) and is about 150 km from Akure, the capital city of Ondo State, Southwestern Nigeria. Also, it is within the 120 km long and about 5-6 km wide belt of tar sand outcrop which trends approximately East-West. The stratigraphic setting of the study area is shown in Figure 2.

2.1 Selected Locations and Sample Collection

The sediments associated with, and overlying the tar sand deposit at Loda Village, Southwestern Nigeria were sampled for geotechnical tests. Lateritic soil samples and fine alluvial sand samples were obtained from the study area. These two lithologies were observed to be overlying the tar sand deposit at the three sample locations. These are 200m apart. These samples were collected from three different points on a road cut at three locations (L₁, L₂, L₃) at Loda Village.

Moreover, at each location, samples were collected from the basal part of the road cut to the topmost part.

AGE	FORMATION		LITHOLOGY
		Alto et al. 1990	Ornatola and Adegoke 1981
CRETACEOUS	EOCENE	Iro formation	Iro formation
		Oshosun Formations	Oshosun formation
	PALEOCENE	Ewekoro formation	Ewekoro formation
MARSSTRICHTIAN	ABEKUTA FORMATION	ABEKUTA GROUP	Araromi
TURONIAN			Afowo
BERREMIAN			Ise
PRECAMBRIAN	BASEMENT COMPLEX		

Figure 2: Stratigraphic setting of the Dahomey Basin, Southwestern Nigeria (Modified from Idowu et al. 1993).

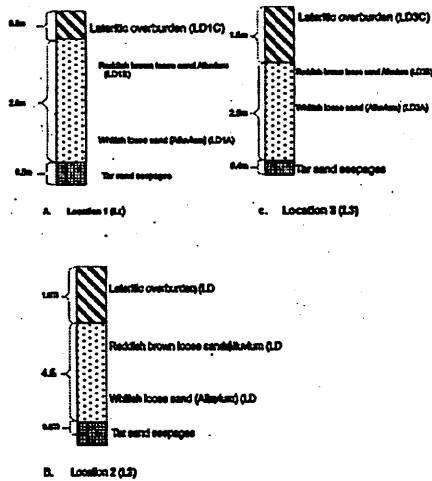


Figure 3a, b and c Lithologic section of three locations L₁, L₂, and L₃ where samples were collected.

2.1 Geotechnical Tests

The unit weight, cohesion and angle of internal friction are essential values necessary for factor of safety determination and the SLOPE/W software analytical tool. The tests carried out on the samples were grain size analysis, density determination and direct shear test. The grain size analysis was carried out using the mechanical dry sieve method in accordance with B.S. 1377, (1990). The density bottle was used to determine the density of the samples while the direct shear test was carried out using the

shear box machine which accommodates 60 mm soil sample and is 20 mm high.

2.3 Computer Modelling

For the computer modelling the Slope/W software was used, courtesy of Geoslope International (Alao and Bassagi, 2007, 2009).

Hypothetical bench dimensions of 10 m and 20 m were used separately with the same bench height of 6 m for both. The bench face angles were increased from 10° to 90° and factor of safety values were calculated using the Morgenstern Price method of analysis. Groundwater levels of 1 m, 4 m and greater than 40 m were utilized separately for each of the bench width used. This is necessary due to the prominent role inundation plays in slope stability. (Alao and Bassagi, 2009).

3.0 RESULT AND DISCUSSION

3.1 Modelling of Bench Face Angles

Shroeder and Dickenson (1996) observed that in order to estimate factor of safety (which is the measure of stability or instability) for any slope surface, the shear strength parameters, slope geometry and groundwater level must be determined level must be determine or defined. The Geostudio SLOPE/W was used to model the different bench face angles cut into the two lithologies overlying the tar sand deposit in the study area. Table 1 shows a summary of the geotechnical data inputted into the SLOPE/W computer program.

Table 1: Summary of data used in the Geostudio SLOPE/W Computer program for the calculation of factors of safety values at various bench face angles

	Average unit Weight Values (kN/m ³)	Average Cohesion Values (kPa)	Average angle of internal friction values (degrees)
Layer 1- Lateritic Soil	25	45	41
Layer 2 Alluvium (Loose sand)	18	0	34

Also, groundwater levels used were based on the two seasons that exist in the study area. For the dry season which extends from November to April, the groundwater level used for the modelling was 4m, while 1m was used for the wet season which runs from May to October. All these parameters and conditions were inputted and factor of safety values were obtained for the different bench width dimensions and bench face angles. Diagrams showing a pass at bench face angle determination and how excavation might be planned for a proposed open pit mine at the study area is shown in figure 4.

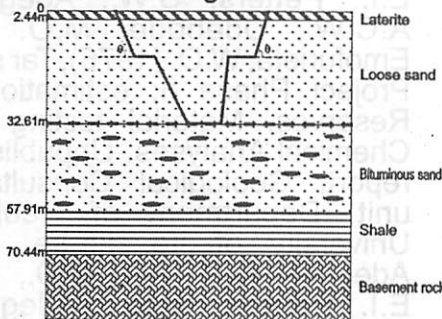


Figure 4: Diagram showing a pass at how excavation might occur from different bench face angles at the study area when mining commences. (Modified from Bitumen Project Implementation Committee Report, 2002)

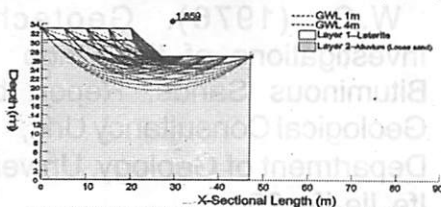


Figure 5: Simulation of 400 slope angles to determine the corresponding factors of safety values for different ground water levels.

However, the great influence that groundwater level or groundwater pressure has on open pit mine stability is expressed in the values obtained for various ground water levels used in Tables 2 and 3. It can be observed that the factor of safety values are high for very deep groundwater level conditions (which is safer) than those of shallow groundwater depth conditions. In open pit mining practice more than 40% of slope instability risk depends on ground water conditions in the slope. Also gave a factor of safety range of 1.2 to 1.4 for rock slopes in open pit mines. Thus, for soil slopes such as those in the area higher factor of safety values must be proposed.

Consequently upon this the factor of safety values obtained from tables 2 and 3 for bench face angles of 10° to 30° are safer than those above 30°. This range is chosen to allow for groundwater level fluctuations due to inundation.

3.2 Recommendations

The two lithologic units overlying the tar sand deposit at Loda village were sampled with geotechnical tests carried out to determine the parameters necessary for slope stability analysis as it relates to future mining operations on the tar sand deposit of Southwestern Nigeria, using Loda village, Ondo State, Southwestern Nigeria, as a case study.

The crucial engineering problem of slope instability or stability has been simulated to determine the bench face angle that would be safe for excavating the lithologies overlying the tar sand deposit at the study area. A proposed open pit at Loda village, Ondo State, Southwestern Nigeria. The following measures need to be put in place in the design and operation of the mine:

1. Installation of piezometer in investigative boreholes to measure the water pressure constantly.
2. Benches must be surveyed regularly to see if small movements are taking place.
3. The use of state-of-the-art monitoring equipment like extensometer is suggested.
4. Digging of wide perimeter trenches which would help to provide good drainage network for the flow of surface water from rainfall and groundwater from the subsurface in the proposed mine.

5. The use of submersible pumps for dewatering (is recommended).
6. The need to carry out Core drilling To have a large data base for detailed and accurate calculations of safety factors.

Table 2: Table showing factors of safety values obtained for different models of bench face angles using a bench width of 10meters and bench height of 6metres.

SLOPE ANGLE (IN DEGREES) ^o	MORGENSTERN-PRICE METHOD OF ANALYSIS		
	1m Piezometric level	1m Piezometric level	Very deep Piezometric Level (>4m)
10	3.37	3.91	4.20
20	2.03	2.26	2.44
30	1.58	1.61	1.82
40	1.35	1.29	1.58
50	1.18	1.37	1.51
60	1.06	1.24	1.36
70	0.79	1.22	1.25
80	0.66	1.07	1.15
90	0.35	1.02	1.09

Table 3: Table showing factors of safety values obtained for different models of bench face angles using a bench width of 20meters and bench height of 6.

SLOPE ANGLE (IN DEGREES) ^o	MORGENSTERN-PRICE METHOD OF ANALYSIS		
	1m Piezometric level	1m Piezometric level	Very deep Piezometric Level (>4m)
10	3.68	4.20	4.51
20	2.41	2.66	2.72
30	1.73	1.65	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	0.63	1.18	1.25
90	0.69	1.02	1.09

4.0 CONCLUSION

The lithologic units overlying the shadow tar sand occurrence at Loda village, Ondo State, Southwestern Nigeria was sampled and tested.

A range of bench face angles, 10° - 90° for future mining operations on the tar sand deposit of Southwestern Nigeria was tried. Adherence to slope angles ranging between 10o and 30o with controlled groundwater conditions were proved to ensure safe mine slopes with minimum instability risk, thereby optimizing the operations of open pit mine for maximum economic gain of the tar sand deposit.

Detailed geotechnical tests that relate to slope stability analysis were not carried out. This research work has gone a bit further than the earlier apporacohes which was based on approximations of geotechnical properties on two lithologies overlying the tar sand deposit at a designated location.

Also, the computer software was used to model the bench face angles that would be appropriate for safe excavation in the tar sand deposit.

However, increasing the slope angle decreases the stability of slope although his depends on the geologic structure and soil and rock properties involved. An attempt has been made in the designing the best bench face angles for excavation.

ACKNOWLEDGMENT

This report is an outcome of the support of several students who helped with field and laboratory data collection (2004 - 2007). I remember that class of 2005, the final year project students who assisted Mr. Mopa Bassagi and the author at Loda village and other places in Dahomey basin. The Logistic support of Professor Ogunlela is gracefully acknowledged. The contributions of NCAM Staff and Mr. Sayomi (Aegis Computer) are invaluable. The author is grateful to Mrs. Bolanle Dara for typing this manuscript.

REFERENCES

- Adegoke, O.S., Ako B.D., Enu, E.I., Petters, S.W., Adegoke, A.C.W., Odebode, M.O. and Emofurieta, W.O. (1976). Tar sand Project Phase II; estimation of Reserves, Material testing and Chemical Analyses. Unpublished report, Geological Consultancy unit, Department of Geology, University of Ife, Ile-Ife, 75p.
- Adegoke, O.S., Ako, B.D., Enu, E.I. Petters, S.W., Adegoke, A.C.W., Odebode, M.O. and Emofurieta, W.O. (1976). Geotechnical Investigations of the Ondo State Bituminous Sands. Report by the Geological Consultancy Unit, Department of Geology, University of Ife, Ile-Ife, 25p.

Adegoke, O.S., Ako, B.D., Enu, E.I. Petters, S.W., Adegoke, A.C.W., Odebode, M.O. and Emofurieta, W.O. (1976). Geotechnical Investigations of the Ondo State Bituminous Sands. Report by the Geological Consultancy Unit, Department of Geology, University of Ife, Ile-Ife, 25p.

Adegoke, O.S. and Ibe, A.C. (1982). The Tar sand and Heavy Crude Resources Nigeria. Proceedings of the 2nd International Conference on Tar sand and Heavy crude, pp. 280-285.

Alao, D.A. and Kareem J.T (2004) Variation in texture and strength of Nigerian Tar sand: Implication of E & P of the Niger Delta Deep Water NAPE-AAPG Conference, Abuja, Book of Abstracts pp A6.

Alao, D.A. (2004). Nigerian Tar Sand: Potential for direct application in road permanent design and construction. Unpublished research document Department of Geology and Mineral Services, University of Ilorin, Ilorin, Kwara State, Nigeria.

Alao, D.A. (2006). Geotechnical Appraisal of a Gully at Zambufu, Kwara State. A poster presentation at AEG Conference, "From till to fill" (October 30 - November 4, 2006). Boston MA, USA.

Alao, D.A. and Bassagi, M. (2007). Computer simulation of slope stability safety factors for tar sand quarrying at Loda Village, Ore, Southwestern Nigeria. Poster Presentation at 50th Anniversary Conference of AEG Los Angeles California, USA.

Alao D.A. and Bassagi M. (2009). Modelling safety factors of slope stability in a tar sand quarry: A case study 1st Annual Civil Engineering Conference, University of Ilorin, Nigeria 26-28 August, 2009.

Bassagi, M. (2007). Computer simulation of slope stability safety factors for tar sand quarrying at Loda Village, Ore Southwestern Nigeria. 162p. M.Sc. Thesis submitted to Department of Geology and Mineral Sciences, University of Ilorin. (Unpublished).

British Standard 1377 (1990): Method of testing soil for Civil Engineering Purposes. Britain Standard Institute London, 152p.

Coker, S.J.I. (1990) Exploration of the Nigerian Oils and deposits in B.D. Ako and E.I. Enu (eds) Occupancy utilization and economics of Nigerian tar sands NMGS Ibadan Chapter Publication pp.30 49.

Duncan, C.W. and Wyllie, C.W. (2004), Rock Slope Engineering. 4th edition, Spon Press, UK. 480p.

Enu, E.I. (1985). Textural Characteristics of the Nigerian Tar Sands. Sedimentary Geology Vol. 44, pp. 65 81.

Enu, E.I. Adegoke, O.S., Robert, C., Ako B.D., Ajayi, T.R., Adediran, S.A. and Oriyomi, A. (1981). Clay mineral distribution in the Nigeria tar sand sequence. In Van Olphen and F. Variable (Eds.). International Clay Conference, 1981 Development in Sedimentology, 35. Elsevier Amsterdam, pp 321 323.

Mandzic E.H. (1992). Mineral Water Risk in open pit slope stability. Mine water and the environment, Vol. II, No 4, pp. 35 42.

Nwachukwu J.I. (2003). Exploitation of the Bitument Deposits of Nigeria. In A.A. Elueze (Ed) Prospects for Investments in Mineral Resources of Southwestern Nigeria. NMGS, Ibadan Chapter Special Publication pp 67 74.