International Journal of Advanced Science and Research
ISSN: 2455-4227, Impact Factor: RJIF 5.12
www.allsciencejournal.com
Volume 2; Issue 2; March 2017; Page No. 05-12

Geo-Technical assessment of the Nekede old road borrow pit

[1] Obasi CL, [2] Owuama CO, [*3] Uzoma HC

[1, 2] Department of Environmental Technology, Federal University of Technology Owerri, Nigeria
[3] Department of Environmental Management and Toxicology, Michael Okpara University of Agriculture, Umudike, Nigeria

Abstract

The aim of this study was to assess the Geo- Technical characteristics of Nekede old road borrow pit. The study was focused on pit moisture content, specific gravity, direct shear strength, slope stability and slope factor of safety. The evaporation method and density bottle method was used to determine pit moisture content and specific gravity respectively. Shear strength was determined using box apparatus while slope stability was determined using Swedish method of slices. Results of the analysis showed that the moisture content range of 11.2 – 14.3% was obtained from the sample results. Also the test results showed specific gravity range of 2.68 – 2.71 across the soil layers of the pit.

The shear test showed a shear strength range from 83.3 – 92.7KN/m^2, with angle of friction range of 24 – 27^o and low cohesion range of 3 – 5 KN/m^2 across the pit walls making the soil susceptible to sliding at slightly steep slopes. Result of slope analysis for three failure planes of the pit slope at 20 meters depth gave a tangential component (T) range of 67.6 – 1018.6 KN within the three slides and a low critical safety factor (F) of 0.4 in the first failure plane and an average safety factor (F) of 0.7 for the three planes as a representative for unstable walls of the Nekede old road borrow pit. This shows that under saturated condition the pit walls collapses. Reconstruction of the borrow pits to suitable dimensions with proper sloping for easy draining was recommended so as to use the site as fish farms using the nworie river as source of water.

Keywords: slope, stability, pit, shear strength and safety factor

1. Introduction

Borrow pit is a term used in construction industry to describe an area where materials such as soil, gravel or sand are being excavated for use in another location. Borrow pit is a site where materials suitable for filling, surfacing or blending can be removed using earthmoving equipments. The greatest yardage of pit material for theatre -of- operations construction is taken from this type of pit. Borrow pits should be worked dry (US Army Tech. Manual, 1967) [26].

A borrow pit, also referred to as a sandbox, is a large hole that has been dug for a particular purpose. The hole left behind after the material has been harvested from a construction site is called a "borrow pit." Frequently, construction crews will dig borrow pits in order to gather gravel, soil, and sand for use in another location. The digging of a borrow pit falls under the engineering discipline known as *earthworks*. Earthworks projects consist of engineering feats that include transporting large amounts of soil or rock from one area to another. Borrow pit construction may seem relatively easy to accomplish, though this type of digging actually requires an extensive amount of analysis prior to the first dig. Engineers must be sure that the amount of soil dug from a pit in an area will not disrupt the earth. This is a specific type of engineering, called *geotechnical engineering*, and is a complex process. Prior to the invention of the computer, geotechnical engineers need to calculate the degree to which the earth would shift during digging. Today, computer programs make these types of calculations simpler. Since massive quantities of earth must be moved in order to build roads, railways, canals, buildings, and other structures, the invention of various industrial tools has made this task easier. Bulldozers, loaders, production trucks, graders, and many other large pieces of equipment are often used to move soil from one place to another. Without these machines, digging a borrow pit would take years instead of months or weeks to accomplish.

A borrow pit's volume really depends upon the construction project at hand. While major roads and freeways may take multiple tons of gravel to build, small projects may not require much soil. (wisegeek article on borrow pit, June 4, 2013)

According to NLUG. (2008) [16], Pits and quarries are used to extract granular resources, as defined in Table 1. Granular materials are often used for construction, but some materials have other uses, such as carving.

2. Materials and Methods

The borrow pit is located at about 150 meters off Old Nekede Owerri, Imo State and about 15 meters to Nworie river course as shown in figure 1 - 3. Owerri the 'Eastern Heart-land' lies between longitudes 6°55 'E to 7°15'E and latitudes 5°15'N to 5°35'N, covering an area of about 1340 km^2. According to Amadi *et al.* (2010), the area is generally flat with a good road network and population of 300,000 people.

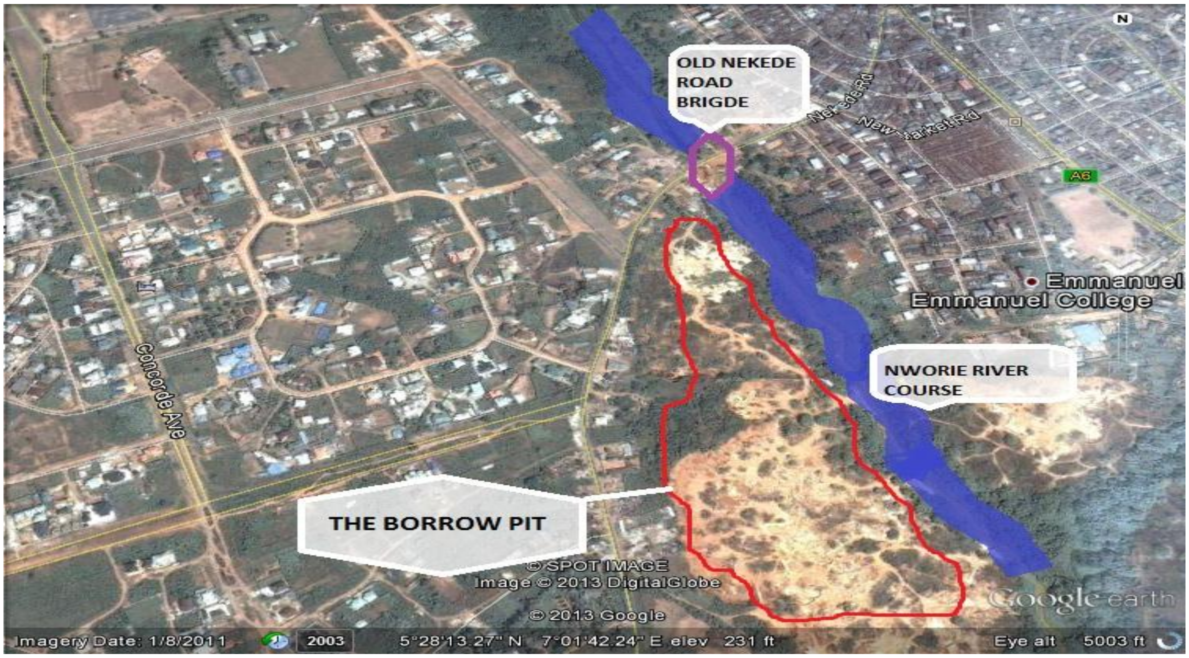

Fig 1: Satellite Map of the study area (Source: google earth, 2011.)

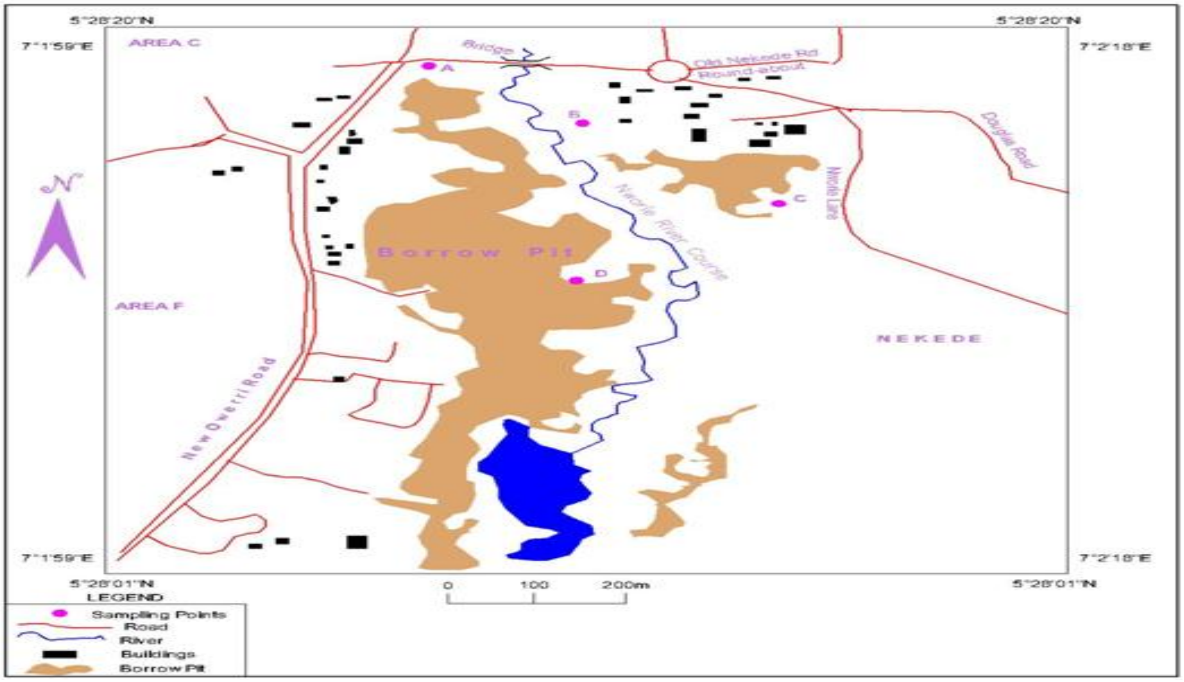

Fig 1: Map of the Study area showing the Borrow Bit.

2.1 Moisture content (W)

Moisture content (W) is the mass of water which can be removed from the soil by heating at 105°C, expressed as a percentage of dry mass of soil.

Sample preparation for moisture content.

- **Apparatus:** Materials used for the test include the following: drying oven maintained at 105°C, desiccators containing anhydrous silica gel, weighing balance (0.01g), moisture content cans, labeling materials, scoop and trimming knifes.
- **Procedure:** The container was weighed empty and recorded. A representative sample was collected using the scoop and placed in the container. The weight of the container and the sample was determined and recorded. The container plus the sample was placed in the oven maintained at 105°C for 18hours.

Also, the container plus dried sample was transferred to the desiccators for cooling. Then, the weight of the sample plus the container was subsequently computed using

$$W = \frac{mass\ of\ water}{mass\ of\ dry\ soil}\ X\ \frac{100}{1} \qquad (3.3)$$

2.2 Specific Gravity (Gs)

This is the ratio between the mass of dry solids and the mass of distilled water displaced by the dry soil particles. It is also called relative density.

i.e. $$Gs = \frac{weight\ of\ dry\ soil}{weight\ of\ equal\ volume\ of\ water} \qquad (3.4a)$$

Sample preparation for Specific gravity (Gs)

Determination of specific gravity Gs using "density bottle method"

- **Apparatus:** density bottle (50ml) with stoppers, constant temperature water bath, volume desiccators, oven and moisture content apparatus, weighing balance (0.001g), wash bottle, spatulas, and riffle box.
- **Procedure:** The density bottle was washed and dried in the oven at 105°C. The mass of the bottle plus the stopper (M1) was determined and recorded. Then the dried sample was placed in the bottle. The weight of the bottle +the stopper + the soil (M2) was determined and recorded. The distilled water was then added to the soil so that the soil was covered and the bottle was about half full. The bottle (without the stopper) was then placed in the desiccators for about 18hours. Air was removed from the soil by releasing the vacuum and carefully stirring the soil in the bottle with the spatula. The weight of the bottle +the stopper + the soil + the liquid, (M3) was then determined and recorded. Also the weight of the bottle +the stopper+ liquid (M4) was also determined and recorded.

The specific gravity Gs was computed using the formula

$$Gs = \frac{Gl(M4-M1)}{(M4-M1)-(M3-M2)} \qquad (3.4b)$$

Where M1 = Weight of bottle + stopper (g)
M2 = Weight of bottle + stopper + soil (g)
M3 = Weight of bottle + stopper + soil + water (g)
M4 = Weight of bottle + stopper + water (g)
GL = Specific gravity of water

2.3 Pit Characteristics

In-situ Measurements

At the field, the average depths and widths of the pit were measured and the depths of excavations are 20-35m and widths are 680-950m with Nwaorie River flowing across the pit. The estimated excavation point is 150 meter to Nekede Old Road and 80-110m to buildings along the Road.

2.4 Shear Strength (KN/m^2)

The maximum shear stress which the soil can withstand without rupture.

Sample Preparation for Shear Strength

Apparatus: The following equipment were used for the test of shear strength; box apparatus, timing device (stop watch), weight, and means of collecting undisturbed sample.

Soil was prepared to the required moisture content. Then it was packed to the calculated height in shear box, which gives the desired bulk density. Dial gages were adjusted to zero reading; one gage on the proving ring was for measuring the shearing force, while the other was for measuring the movement of the upper half of the shear box for strain calculations. The upper half of the shear box was covered by its gripper plate and the loading bar was adjusted to floot above it to give zero normal loads on the hanger.

2.5 Slope Stability Analysis of the Pit Walls

Slope failure has been a major problem for borrow pit operators and other deep excavation activities since time immemorial.

Besides the examination of the soil characteristics, the depth of the pit and the angle of slope of the pit wall should be well thought out in other to achieve a stable pit walls. Figure 3 illustrates the typical geometry of Nekede old road borrow pit walls with a sliding angle of 51^o at the top and 39^o at the base. The pits have an average critical depth of 20m where it appears to be stabilized due to increased slide embankment.

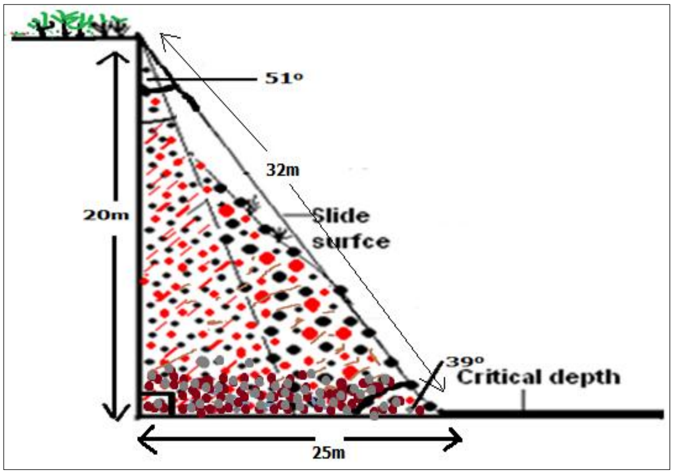

Fig 3: Typical Geometry of the pit walls.

Swedish method of slices was deemed suitable for slope analysis of the Nekede old road borrow pit walls. Assuming the soil is saturated and where the soil has both values of ϕ and C, this total stress analysis can be adapted to cover the case by assuming a slip circle procedure and dividing the sector into a suitable number of vertical slices. This method is applied by taking moments about the center of rotation O of an arc made over the slope. The failure plane is then divided to a number of slices.

The Disturbing moment is
= rΣT and the Restraining moment is
= r(crθ+ΣNtan ϕ).

Factor of safety F = Restraining moment / Disturbing moment

Hence, $$F = \frac{Cr\theta + \Sigma N \tan \emptyset}{\Sigma T} \qquad (4.1a)$$

While N = W$\cos\beta$ and T = W$\sin\beta$.

The effective tension crack can also be allowed for in this case if there are significant cracks.

$$h = \frac{2c}{\gamma}\tan(45° + \frac{\emptyset}{2}). \qquad (4.1b)$$

Where F is the factor of safety, C is the cohesion, r is the radius of the arc, θ is the angles of slope of the slide, h is the height of the crack, γ is the unit weight of soil, N is the normal component, T the tangential component, W the weight of each slice and $\emptyset$ is the angle of internal friction.

3. Results and Discussion

Moisture Content and Specific Gravity Analysis

Moisture content: The average moisture content of the samples from the pits is 12.9% with the sample at the base of the pit having the highest of 14% as shown in table 1. These figures will get higher in the wet seasons.

Specific gravity: The test results shows average specific gravity of 2.69 across the soil layers of the pit as shown in table 2. This shows that the soils of this pit are predominantly sandy since generally, specific gravity of sandy soils is 2.65.

Table 1: Moisture Content

Sample	Unexcavated	pit base	7m	10m	15m
Wt. of wet sample + Can (g)	67.3	67.7	63.7	63.8	65.0
Wt. of dry sample + Can (g)	62.8	62.0	58.7	59.0	60.4
Wt. of Can	19.1	22.1	21.5	20.6	19.3
Wt. of dry soil (g)	43.7	39.9	37.2	38.4	41.1
Wt. of Water (g)	4.5	5.7	5.1	4.8	4.6
Water Content, W (%)	10.3	14.3	13.7	12.5	11.2

Table 2: Specific Gravity (Gs) test.

Sample	Unexcavated	pit base	7m	10m	15m
M1	56.9	56.8	56.8	56.9	56.7
M2	67.0	66.9	66.9	67.0	66.9
M3	162.3	162.3	162.1	67.0	66.9
M4	155.9	155.9	155.8	155.9	155.7
Gl	1.00	1.00	1.00	1.00	1.00
Gs	2.70	2.71	2.68	2.68	2.70

M1 = Wt. of bottle + stopper (g)
M2 = Wt. of bottle + stopper + soil (g)
M3 = Wt. of bottle + stopper + soil + water (g)
M4 = Wt. of bottle + stopper + water (g)
Gl = specific gravity of water
Gs = specific gravity of substance.

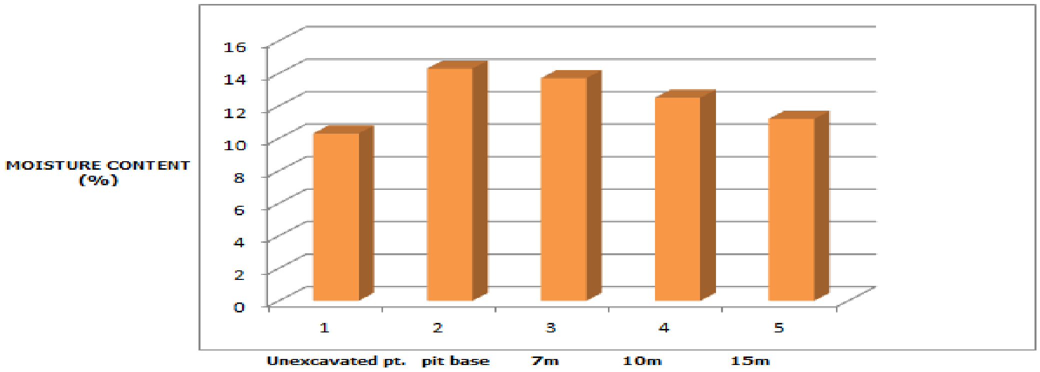

Fig 4: Shows variations in moisture content among the samples analyzed

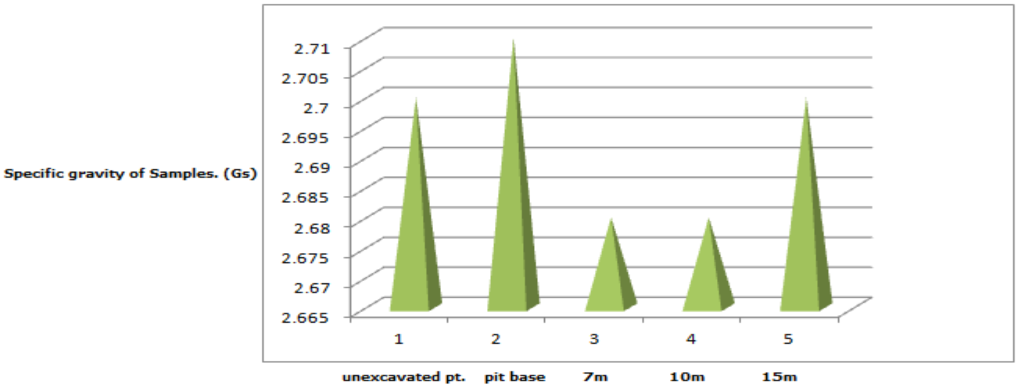

Fig 5: Shows variations in specific gravity among the samples analyzed

Shear Strength Test Analysis

Figures 6 - 10 below are graphs that illustrate the result of shear test for the samples tested. The shear strength (τ) of the samples were calculated using $\tau = C + \sigma_n \tan \phi$ and a range of 83.3 – 92.7 KN/m^2 were obtained across the pit walls with a cohesion range of 3 – 5 KN/m^2 while a shear strength of 92.7 KN/m^2 and cohesion of 6 KN/m^2 were obtained for the sample at unexcavated point as shown in table 3. Because of the high percentage of sand across the pit walls, the pore spaces within the soil matrix are high. In wet seasons, this can trap and store water within it which will increase the shear stress on the pit walls.

However, Hardy (2007), noted that due to the flotation effects of water, all soils including gravel lose about 50% of their apparent shear resistance to sliding when fully saturated. In contrast plastic soils, including clay-like tills, could lose 99.5% of their total shear resistance to sliding due to equally modest alterations of slope drainage.

Direct Shear Test

a) Sample Dimensions (for all samples)

Length (L) = 60mm
Width (w) = 60mm
Height (H) = 20mm
Area (A) = L x W = 60 x 60 = 3600mm^2
= 0.0036m^2
Volume of sample (V) = L x W x H = 60x60x20=7200mm^3

b) Normal stress computation (σ) KN/m^2 (For all samples)

Table 3

(1) Load (kg)	(2) Load (KN) = (1)÷100	(3) Area (m^2)	(4) δ (KN/m^2) = (2) ÷ (3)
24	0.24	0.0036	66.7
44	0.44	0.0036	122.2
64	0.64	0.0036	177.8

c) Shear Stress (Ʈ) Computation (KN/m^2)

Table 4

(1) Sample	(2) Load (kg)	(3) Max. H.R	(4) = (3) x 0.002 (MM)	(5) = (4) x 0.88(KN)	(6) = (5) ÷A (KN/m^2)
Unexcavated	24	86	0.172	0.151	42.0
	44	147	0.294	0.259	71.9
	64	225	0.45	0.396	110.0
Pit base	24	78	0.156	0.137	38.1
	44	135	0.27	0.238	66.0
	64	194	0.388	0.341	94.8
7m	24	86	0.172	0.151	42.0
	44	137	0.274	0.2412	67.0
	64	200	0.40	0.352	97.8
10m	24	82	0.164	0.144	40.1
	44	143	0.286	0.252	69.9
	64	210	0.42	0.3696	102.7
15m	24	82	0.164	0.144	40.1
	44	151	0.302	0.266	73.8
	64	220	0.44	0.387	107.6

Table 5: Summary of the shear strength analysis.

Sample	C (KN/m^2)	$\phi(^0)$	σ_n (KN/m^2)	(Ʈ) (KN/m^2)
Unexcavated	6	26	177.8	92.7
Pit base	3	25	177.8	85.9
7m	4	24	177.8	83.2
10m	5	25	177.8	87.9
15m	3	27	177.8	92.7

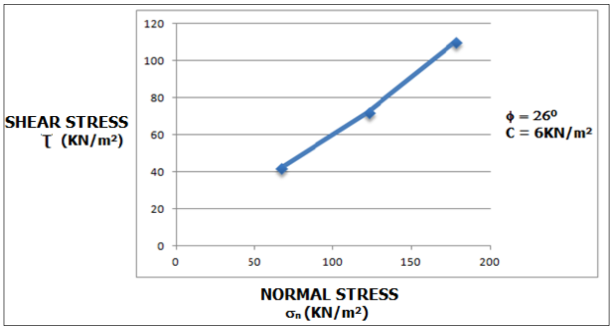

Fig 6: Shear strength for Sample at Unexcavated point.
Average shear strength: 92.7KN/m^2

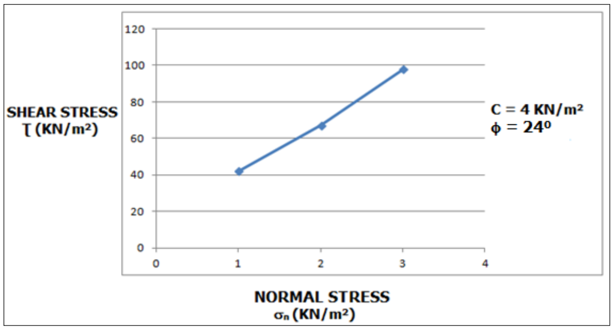

Fig 8: Shear strength for Sample at 7m.
Average shear strength: 83.2KN/m^2

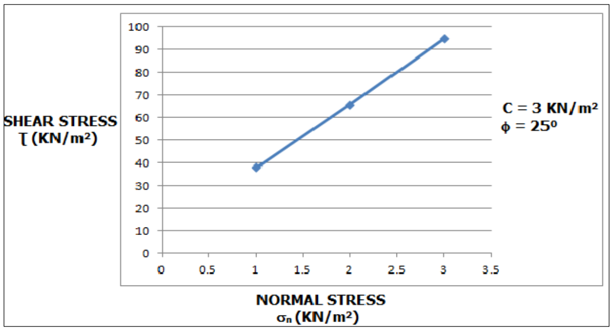

Fig 7: Shear strength for Sample at pit base.
Average shear strength: 85.9KN/m^2

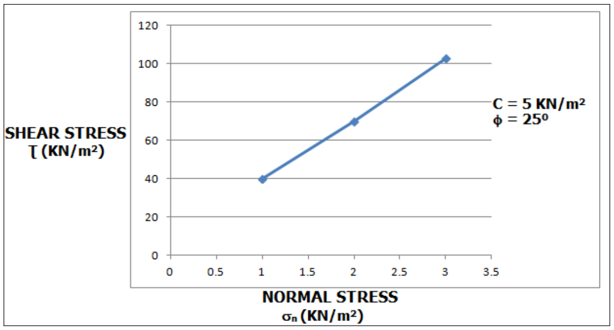

Fig 9: Shear strength for Sample at 10m.
Average shear strength: 87.9KN/m^2

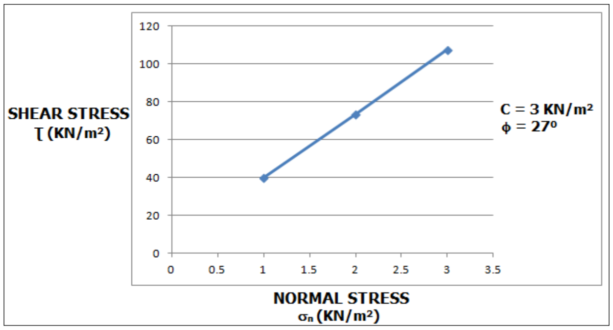

Fig 10: Shear strength for Sample at 15m.
Average shear strength: 93.6KN/m^2

Slope Stability Analysis of the Pit Walls

For a detailed slope analysis of the Nekede old road borrow pit walls, three moments were taken about three different centers of rotation O1, O2 and O3 of three arcs made over the slope of 20m depth to obtain three failure planes (Three slides). These arcs were made at 2m apart from each other and were separately divided into four slices where their heights (h), widths (b) and the angles of slope for each slice (β) were determined as shown in tables 6-8.

The calculation of the factor of safeties (F) for the three slides shows a variation in the values of F (0.4, 0.5 and 1.2) with an average mean value of F as 0.7 as shown in table 9. With this average mean value of the factor of safety below 1.0 the walls of this pit were then deem to be unstable and highly susceptible to failure.

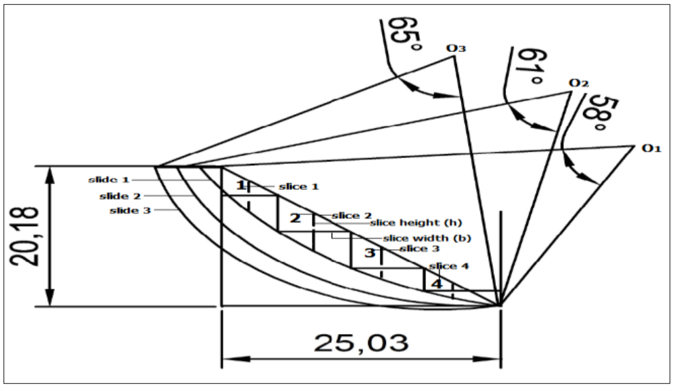

Fig 11: Pattern of slices

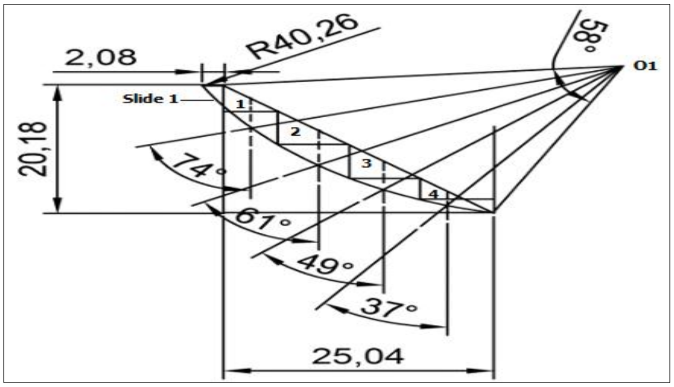

Fig 12: analysis of slices in slide 1

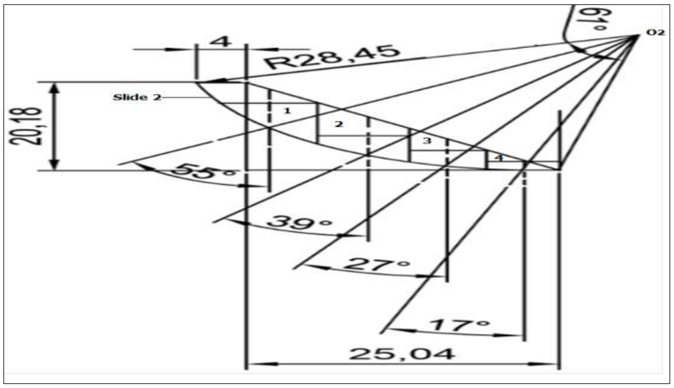

Fig 13: analysis of slices in slide 2

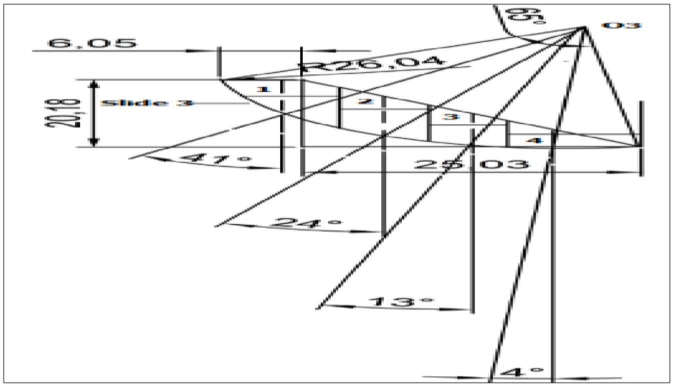

Fig 14: analysis of slices in slide 3

Table 6: slices analysis table for slide 1.

S. no	Slice Height h (m)	Slice width b (m)	β(⁰)	Area of slice (m^2)	Slice weight W (kN/m^2)	Normal Component N (kN)	Tangential component T (kN)
1	4.8	5.0	74	24.0	456.0	125.6	438.3
2	5.3	6.5	61	34.4	654.5	317.3	572.4
3	4.4	6.9	49	30.3	576.8	378.4	435.3
4	2.3	6.8	39	15.6	297.1	237.2	179.7
						ΣN = 1058.5	ΣT =1625.7

Where radius r for slide 1 is 40m, average angle of internal friction ∅ is 25^0 and the average cohesion C of the pit soils is 4 kN/m^2.

Therefore factor of safe F is

$$F = \frac{cr\theta + \Sigma N \tan\emptyset}{\Sigma T}$$

$$cr\theta = 4 \text{ x } 40 \text{ x } \frac{58}{180} \text{x } \pi = 161.9\text{kN}$$

$$\Sigma N \tan\emptyset = 1058.5\text{x } \tan 25 = 493.5\text{kN}$$

$$F = \frac{161.9+493.5}{1625.7} = 0.4$$

Table 7: slices analysis table for slide 2.

Slice no.	Slice Height h (m)	Slice width b (m)	$\beta(^0)$	Area of slice (m^2)	Slice weight W (kN/m^2)	Normal Component N (kN)	Tangential component T (kN)
1	8.5	7.7	55	66.4	1243.5	713.2	1018.6
2	8.7	7.3	39	63.5	1206.6	937.7	759.3
3	6.0	6.1	27	36.5	695.3	619.5	315.6
4	2.1	5.8	17	12.1	231.4	221.3	67.6
						ΣN = 2491.7	ΣT = 2161.1

Where radius r for slide 2 is 28.4m, average angle of internal friction ∅ is 25^0 and the average cohesion C of the pit soils is 4 kN/m^2.

Therefore factor of safe F is $F = \frac{cr\theta + \Sigma N \tan \emptyset}{\Sigma T}$

$$cr\theta = 4 \text{ x } 28.4 \text{ x } \frac{61}{180} \text{x } \pi = 120.9\text{kN}$$

$$\Sigma N \tan \emptyset = 2491.7\text{x } \tan 25 = 1161.8\text{kN}$$

$$F = \frac{120.9+1161.8}{2161.1} = 0.5$$

Table 8: slices analysis table for slide 3.

Slice no.	Slice Height h (m)	Slice width b (m)	$\beta(^0)$	Area of slice (m^2)	Slice weight W (kN/m^2)	Normal Component N (kN)	Tangential component T (kN)
1	10.0	7.2	41	72.0	1368.0	1032.4	897.4
2	11.8	6.6	24	77.8	1479.7	1351.7	601.8
3	9.2	5.8	13	53.3	1013.8	987.8	228.0
4	5.8	9.8	4	56.8	1079.9	1077.2	75.3
						Σ= 4449.1	ΣT = 1803.2

Where radius r for slide 3 is 26m, average angle of internal friction ∅ is 25^0 and the average cohesion C of the pit soils is 4 kN/m^2.

Therefore factor of safe F is

$$F = \frac{cr\theta + \Sigma N \tan \emptyset}{\Sigma T}$$

$$cr\theta = 4 \text{ x } 26 \text{ x } \frac{65}{180} \text{x } \pi = 117.9\text{kN}$$

$$\Sigma N \tan \emptyset = 4449.1\text{x } \tan 25 = 2074.6\text{kN}$$

$$F = \frac{117.9+2074.6}{1803.2} = 1.2$$

Table 9: mean of the factor of safeties

Number of slides	Factor of safety (F)
Slide 1	0.4
Slide 2	0.5
Slide 3	1.2
Mean	0.7

The soils of Nekede old road borrow pits are predominantly sandy with low cohesion and completely non plastic. These natures of the soil contribute to a greater extent of the slope failures in the pit.

The critical factor of safety of 0.7 as obtained from the slope analysis is a representative of the slopes of the pits and thus the pit walls were deemed to be unstable. This shows that under saturated condition the pit walls will collapse. The failure of the borrow pit walls are generally initiated by excavation depths exceeding 15 meters with steep slope angles.

4. Conclusion and Recommendations

The following recommendations were considered for this research;

- **Environmental Impact Assessment:** Road contractors should present environmental impact assessment (EIA) of their road project for approval by the government authority prior to commencement of the project. The report should contain a comprehensive sustainable borrow pit reclamation programme before license to excavate will be granted for the pit operation.
- **EIA implementation:** The government should exercise prudence when it comes to leasing out the land for borrow pit activities and also demarcate areas clearly and monitor excavation through a sustainable geoenvironmental board where stable depths and slope angles will be emphasized.

5. Reclamation

Once excavation is completed, the operator should seal off the pit to deter intruders and commence reclamation at once in the forms as follow;

6. Agriculture

Fish ponds; The borrow pits should be reconstructed to suitable dimensions as fish farms using the nworie river as source of water and sloped for easy draining and replacement of the water.

Irrigated farm lands; As an alternative, the borrow pits should be graded to achieve a semi level farm land and ploughed where all season farming can take place using the nworie river as source of water.

7. Engineering

Engineering retaining walls with steel bars and reinforced concrete should be constructed. This system further stabilizes the pit slopes by providing added resistance against the sliding forces. Runoff should also be diverted away from the pit. Also removing soils from the head of the slope in order to reduce its height and slope inclination are other ways of decreasing the driving forces that causes slope failures then the area should be graded and landscaped to a semi level plane, and could be used as a public car parking lot.

8. References

1. Aesthetics/Visual Resources Impact Assessment, AVRIA. Southern California International Gateway Draft EIR, 2013. Available online at http://www.portoflosangeles.org accessed 15th, June.
2. Agriculture and Resource Management Council of Australia and New Zealand, ARMC. Minimum construction requirements for water bore in Australia in Avbovbo AA. Tertiary Iithostratigraphy of the Niger Delta. Am. Assoc. Petrol. Geol. Bull. 1978-1998; 62:295-306.
3. Australian Mining Industry Council, AMIC. Mine Rehabilitation Handbook. Canberra ACT, 1989. 2600 @ http://www.ag.gov.au/cca
4. Ashraf MA, Mohd. JM, Ismail Y, Abdul W, Karamat M.
5. Sand mining effects, causes and concerns: A case study from Bestari Jaya, Selangor, Peninsular Malaysia, 2011. ISSN 1992- 2248 ©2011 Academic Journals. Available online
   at http://www.academicjournals.org/SRE
6. Colorado Geological Survey, CGS. Landslides in Colorado, 2013. Available online at http://www.geosurvey.state.co.us accessed 14th, June, 2013.
7. Etuonovbe AK. Economic Benefit of Hydrography: Land Reclamation in Bayelsa State: A Case Study of Saipem Camp. Strategic Integration of Surveying Services FIG Working Week 2007 Hong Kong SAR, China, 2007.
8. Federal Department of Agriculture and Land Resources, FDALR. Technical Report on erosion and wetland of south-eastern Nigeria, 1980.
9. Forth HD, Turk LM. Fundamental of soil science (5th ed.) John Wiley and Sons Inc. USA. 1972, 348-355.
10. Fortescue Metal Group. FMG. Pilbara Iron Ore Project, Draft Borrow Bit Rehabilitation Procedure, 2004. Available online at http://www.epa.wa.gov.au accessed 15th, June, 2013.
11. Hardy Bartle. B.C.’s Watershed Restoration Technical Bulletin, streamline journal, 2007, 6. E-mail:Hardy.Bartle@gems5.gov.bc.ca
12. Jencie M, Robinson P, Giummarra G. Environmental Best Practice for Outback Roads Guidelines for Transport SA RC 90165-4, 2000.
13. Kulkarni UD. Impacts and Responses Rate of Siltation in Wular Lake, (Jammu and Kashmir, India) The International Journal of Climate Change: with Special Emphasis on its Climate & Tectonics, 2009.
14. Main Roads Western Australia, MRWA. Environmental Management Guidelines. National Association of Australian State Road Authorities, Main Roads Department and Australian Development Assistance Bureau. East Perth, WA, 1997.
15. National land reclamation policy NLRP. Kenya, 2013. final draft, ministry of water and irrigation, republic of kenya, © february 2013.
16. Northern Land Use Guidelines NLUG. Pits and Quarries (Draft) Indian and Northern Affairs, Canada, 2008.
17. Nwachukwu MA, Huan F. Environmental hazards and sustainable development of rock quarries, lower Benue trough Nigeria”; oida international journal of sustainable development. 2012; 05:(6):51-68.
18. Onyeagocha AC. Petrography and depositional environment of the Benin Formation, Nigeria. J. Min. Geol. 1980; 17:147-151.
19. Peckenham JM, Thornton T, Whalen B. Sand and gravel mining: effects on ground water resources in Hancock County, Maine, USA. Environmental Geology. 2009; 56:1103-1114.
20. Reyment RA. Aspects of the Geology of Nigeria. Ibadan University Press, Nigeria, 1965.
21. Salgado R, Bandini P, Karim A. Shear strength and stiffness of silty sand. Jour. of Geotech. Geoenviron. Eng., 2000; 126(5):451-462.
22. Short KC, Stauble AJ. Outline geology of the Niger Delta, Nigeria. American Association of Petroleum Geologist. 1967; 5:761-779.
23. Smith P. Soil water conservation in Rowland J.P.T (ed.) Dry land farming in Africa. C.T.A Macmillan, London and Basingtone, 1993, 142.
24. Troeh FR, Donahue DL. Soil and water conservation for productivity and environmental protection. Prentice hall Inc. Englewood Cliff. 1980, 83-110.
25. Tyne River Trust TRT. Siltation and pressures on river habitats in UK, 2012. Available online at http://tyneriverstrust.org accessed 15th, June, 2013.
26. US Army Technical Manual, Pits and quarries investigation, Public document reference department, TM5-332, University of Virginia @ december 1967.
27. Virdi KS. Abnormal Loading on Structures: Experimental and Numerical Modelling. Taylor & Francis. 2000, 108. ISBN 0-419-25960-0.
28. Walden JF. Conservation and Regeneration Techniques, Road Construction and road Maintenance. 1982, 4.
29. Wisegeek article on borrow pit, 4, 2013.