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Slope Stability Assessment: A Case Study of Embankments Along OMU-Aran-Ilorin Road, Nigeria

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Abstract: The frequent failure of embankment slopes along Omu-Aran-Ilorin road has resulted in the escalation of construction maintenance costs of roads. An approach to reduce the construction maintenance costs of highway maintenance is to ensure that a comprehensive assessment of embankment slopes is carried out during the initial design stage of road projects. The current study therefore provided a site-specific assessment of an embankment slope along Omuaran-Ilorin road. The site-specific soil samples were collected at four points at depth 0.5m and 1.0m and were subjected to index properties and shear strength properties. This was followed by results analysis and interpretation. The index properties reveal that the selected four soil samples are classified as fine –grained soil and examination of the embankment reveal point 3 as best location for slope stability construction while the remaining three location needs improvement and stabilization to be able to use as an embankments. Therefore, this research provided a site-specific geotechnical database for future implementation in the proposed design-recommendations for Nigerian soils, especially in the southwestern Nigeria. Further contribution of this research is to provide references for local practicing engineers.

I. Introduction

Slope stability assessment is a critical aspect of geotechnical engineering, especially in countries like Nigeria, where natural and man-made slopes are subject to various environmental and anthropogenic pressures. The assessment involves evaluating the potential for slope failure, landslides, and soil erosion, which are frequent hazards in areas with diverse topographies and climatic conditions. Globally, the assessment of slope stability has gained increasing attention due to rapid urbanization, deforestation, agricultural expansion, and the impact of climate change, particularly heavy rainfall.

The current study focuses on the assessment of embankment slopes along Omuaran-Ilorin road, Southwest Nigeria. There are several embankment slopes along the aforementioned road, which when not properly assessed could constitute serious geotechnical hazards for both pedestrians and motorists. The study area is situated along Omuaran-Ilorin road, Kwara State of Nigeria. It lies within longitudes 4.653748^0N and 8.401818^0E. The selected study area for the current study is indicated in Plate 1a and 1b. Several existing international standards have specified the average factors of safety (FoS) for embankment slopes as per drainage (drained and undrained), seismic, and post-seismic site conditions.

II. Materials and Method

The soil samples were excavated from four large pits along Omuaran-Ilorin road, Kwara State of Nigeria. It lies within longitudes 4.653748^0N and 8.401818^0E. 4 bags of soil samples were collected. The soil samples were sealed, and transported to the laboratory and were air dried slowly at room temperature in the laboratory.

Soil samples preparation

Soil samples from burrow pit 1, 2, 3 and 4 were obtained at depths of 0.5m and 1.0m at the existing embankments. The weight of each samples were noted. Each soil samples was apportioned for the various test namely moisture content, specific gravity, atterbergs limits, and particle size analysis, shear strength (direct and indirect) and permeability. In order to facilitate standard laboratory testing, but with representative field composition, the soil samples collected were transported to the laboratory and were air-dried and its particle size distribution were determined using particle size analysis in accordance with BS 1377 (1990) Part 2:9. Specific gravity test was done for the soil samples (< 2.00mm particle size).

Permeability

Constant head hydraulic conductivity tests were performed in accordance to BS 1377 (1990) Part 5. For these tests, soil samples were compacted in the rigid wall permeameter mould (with sample dimensions of 100 mm inside diameter and 200 mm height) using a tamping device. Flow rate under constant hydraulic gradient was measured. Darcy's law was used to calculate hydraulic conductivity.

Shear strength (Direct and indirect)

Tests were conducted to determine the shear strength properties (direct and triaxial tests). The procedures for various tests were carried out in accordance with BS 1377 – 1990:1-8. A triaxial test is performed on a cylindrical core soil or rock specimen to evaluate its shear strength. The cylindrical soil sample is prepared in the laboratory using a proper mould, the specimen is generally saturated and has a depth ranging from 38mm to 100mm. The height to diameter ratio of the sample is generally.

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The cylindrical soil specimen is vertically sealed within a thin rubber membrane and placed between two porous discs at the top and bottom end, the cylindrical soil sample is then positions between loading plates and placed on a pedestal inside a Triaxial pressure chamber which is filled with water which applies fluid pressure to the sides of the cylindrical soil sample and axial stress is applied to the cylindrical sample by applying force to the moveable top loading plate.

III. Results and Discussion

Results of index properties of the selected soil samples

When it comes to geotechnical and highway engineering, slope stability is crucial, especially in places where natural soil is used to build embankments or cut slopes. In order to ascertain the implications of laboratory test results on slope stability, four distinct sampling points are evaluated in this discussion. Atterberg limits, particle size distribution, specific gravity, and natural moisture content are among the parameters examined and results obtained were presented with table 1.

Table 1: Results of index properties of the selected soil samples

Tests		Pit 1	Pit 2	Pit 3	Pit 4
Natural Moisture content		15.76	14.60	15.87	13.01
Specific gravity		2.48	2.47	2.44	2.26
Particle size distribution	% Gravel	16.34	29.72	47.20	34.46
	% Sand	50.02	35.68	19.70	31.58
	% Fine	33.64	34.60	33.10	33.96
Atterberg limit	Liquid limit	26.51	33.80	31.00	34.00
	Plastic limit	8.25	20.40	24.81	20.75
	Plasticity index	18.26	13.40	6.19	13.25
	Shrinkage limit	8.57	9.29	8.57	10.71
AASHTO Classification		A-2-6	A-2-6	A-2-4	A-2-6

The results of the preliminary tests of the selected soil samples is presented in Table 1. Results of natural moisture content as presented in Table 1 shows that the results obtained are high with soil samples from pit 2 and 4 is in agreement with the recommended range of 5-15% (FMWH, 1997) and results from pit 1 and 3 are greater than the recommended range. The results of specific gravity are within 2.26 – 2.48, the value is lesser than 2.60 shows an indication of organic materials in the soil (Wright, 1985; Amadi et al., 2017). The result of the particle size distribution in percentage weight of soil samples were presented with Figure 1. The percentage of soil passing 75µm sieve shows that the sample are silty or clayey gravel sand material i.e., excellent to good soil (AASTHO, 1986). Atterbergs limits shows the value of liquid limits and plasticity index in percentage. It was observed that the soil samples has liquid limits lesser than 35% which is in conformity with FMWH (1997) for use as fill materials. Also the selected soil samples did not conform to the requirement that plasticity index (PI) should not be more than 12% (FMWH, 1997). Table 1 shows that only soil sample from pit 3 meet the requirement according to AASHTO classification system for use earth fill materials.

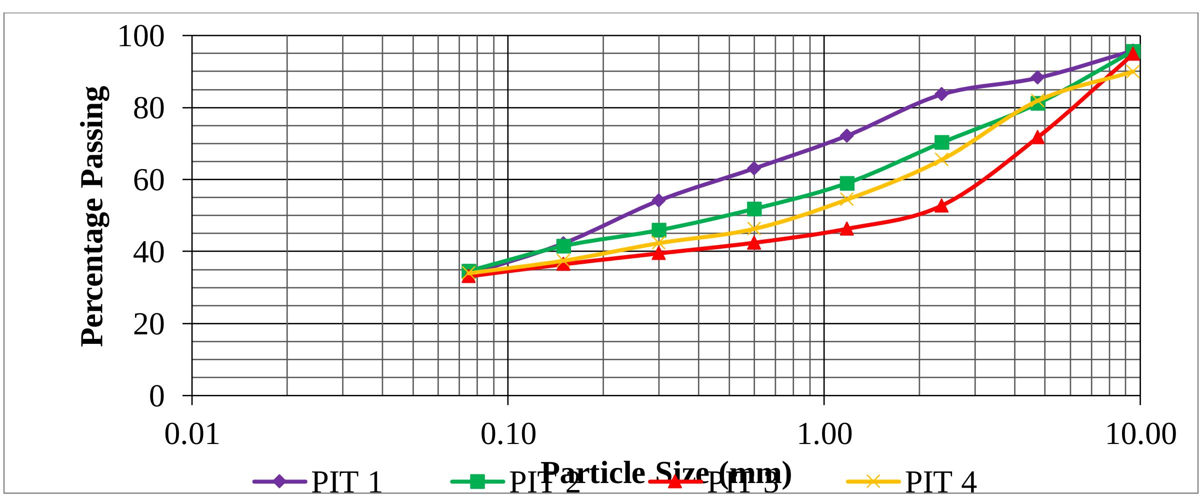

Figure 1: Particle size distribution of the selected soil samples.

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Shear strength (Direct and indirect (triaxial))

Results of direct shear strength was presented with table 2 and the results reveal that generally, depth increases cohesion as well as angle of internal friction. This trend is in line with the observations of Akinwumi et al., (2019), who pointed out that lower weathering and better compaction levels often result in stronger deeper soil layers. Higher shear strength also comes from decreased organic content and better particle interlocking at depth.

Table 2 Results of direct shear strength of depths 0.5m and 1.0m

Points	0.5m		1.0m	
	C (kN/m²	ϕ (°)	C (kN/m²	ϕ (°)
1	5	23.5	7	29
2	9	22	10	26
3	15	28	13	32
4	18	31	18	34

The triaxial shear strength obtained from the study shows that most of the sampled pits show high short-term slope stability, mainly due of increased values of cohesion (C). Under undrained conditions, especially in fine-grained soils where water movement is limited, cohesion is absolutely essential in offering shear resistance. The cohesive qualities of the soil greatly improve its resistance to deformation and shear failure in the near term—that of immediately following construction or during fast loading events. This is clear at several places, particularly at Pit 3 (0.5 m) and Point 2 (0.5 m), where cohesion values exceed 120 kN/m², so indicating a strong capacity to retain structural integrity under undrained conditions as presented in Table 3.

Table 3: Results of triaxial shear strength of depths 0.5m and 1.0m

Points	0.5m		1.0m	
	C (kN/m²	ϕ (°)	C (kN/m²	ϕ (°)
1	83	15	96	11
2	123	14	102	12
3	181	12	81	15
4	92	23	108	13

Permeability

The results obtained from permeability test carried out on the selected soil from the four pits are analysed as range from 3.09×10^{-7} m/s to 1.12×10^{-6} m/s. Based on standard permeability classification:

I. 10^{-9} to 10^{-6} m/s: Low permeability (typical of clayey and silty soils)

II. 10^{-6} to 10^{-4} m/s: Medium permeability (typical of silty sands)

The tested soils can therefore be categorised as low to borderline medium permeability based on the observed coefficient of permeability values, which range from roughly 3.09×10^{-7} m/s to 1.12×10^{-6} m/s. Soils with permeability coefficients in this range are generally associated with fine-grained materials, such as clayey silts, silty clays, and low-plasticity clays, according to established geotechnical classification systems (e.g. Adam, 2000). Rapid water flow is hampered by these soil types' low hydraulic conductivity and comparatively small pore spaces.

IV. Conclusion

The selected soil samples were examined and showed that pit 1 is not suitable for an embankment due to its high plasticity and low friction angles suggest possible long-term hazards, but high cohesion in the shear strength test results suggests good short-term stability. Pits 3 and 4 reveal long-term and short-term stable soil conditions appropriate for embankment slopes and the permeability results shows that pit q and 2 have inadequate drainage, which might threaten the stability of the slope when it gets saturated.

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