Geomorphology Of Goretti Site And Foundation Parameters For Erosion Control Facility At Ikot Ekpene, AKS, Nigeria

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***Abstract*-Various methods and parameters were considered to aid decision on geotechnical investigation of the Goretti site project. Two deep borings: – First at the tip and the second at base floor of the gully would provide relevant stratification data for design purpose. Four shallow borings were considered adequate to provide needed information in designing required access road into the site. In all the boreholes ten identifiable horizons were noted based on USCS standard. Utilizing SPT-N values for computation of allowable bearing capacity, results derived from first borehole varied from 75.53kPa to 160.50kPa and the second borehole from 169.95kPa to 613.73kPa from a depth of 1meter to 10 meters respectively. The shallow boreholes provided OMC values between 12.1% and 15.6%. MDD values varied from 1720kN/m^{3}to 1890kN/m^{3}and CBR values ranged from 8.9% to 12.8%. These shallow borehole parameters indicate materials not suitable for base course applications. Finally, a cantilevered retaining structure and gabion wire mesh stacking along with trapezoidal concrete drain were recommended as viable options to curtail the erodibility of the gully site.**

Keywords-Gully; Erosion; Borehole; Lithology; Gabion

I. INTRODUCTION

The decision to conduct geotechnical investigation was authorized by Prelim Consulting Ltd. The objective was to investigate the suitability or otherwise of soil formation to aid engineering design of erosion control facility for Goretti Site, Ikot Ekpene, Akwa Ibom State. This is a high school location subjected to gully erosion which is threatening some vertical structures within the area. A geotechnical investigation of the project site was carried out. This was with a view to establishing the sub-soil conditions for the placement of gabion steps embankment with chippings foundation for the eroded portions or any other erosion control facility considered appropriate. An experienced team comprising of geotechnical engineers and drillers undertook the investigation involving drilling two deep borings down to 10m depth and four shallow borings down to 3m depth. The borings were drilled using the shell and auger percussion rig. The soundings (SPT-N values) were carried out at appropriate depth intervals of 1.00 meters or where a change of lithology was observed during the boring process. Soil samples were obtained during the boring process and were later subjected to visual examinations as well as detailed laboratory testing. A light cone penetration test was conducted at tip of eroded portion to determine in-situ soil bearing pressure.

II. PROJECT LOCATION

The project is located within the tropical zone at Ikot Ekpene, Akwa Ibom State in the eastern section of the Niger Delta sub-region of Nigeria. [Fig. 1]. The general topography of the project site is relatively undulating brought about by geomorphology with low areas at back meandering along stream water course. The vegetation is principally that of tropical rain forest but of secondary nature that is prevalent in most parts of the southern Nigeria. Tall trees with thick canopies underlain by thick shrubs and undergrowth characterize the predominant vegetation pattern within the site.

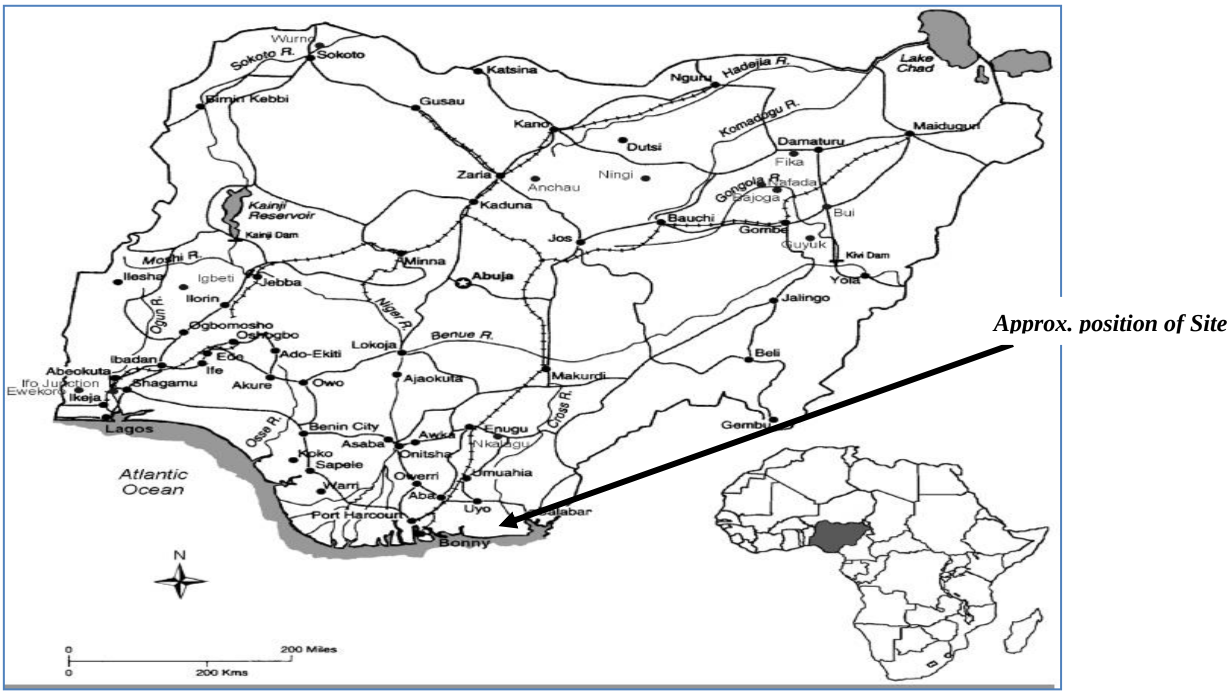

Fig. 1: Location of Project Site at Ikot Ekpene, Akwa Ibom State, Nigeria.

TABLE I: BORINGS DESIGNATE AT THE PROJECT SITE

S/N	Boring No.	Location Description	Coordinate	Elevation(m)
1.	BH 1 (Deep Boring)	Tip of the Gully Section	5˚10'04.95" N 7˚42'21.03" E	42.59
2.	BH 2 (Deep Boring)	Base Floor of Eroded Portion	5˚10'08.29" N 7˚42'19.18" E	23.19
3	BH 3 (Shallow Boring)	Threatened Portion near School Academic Block (1st Roundabout)	5˚10'00.89" N 7˚42'22.28" E	41.69
4	BH 4 (Shallow Boring)	Threatened Portion near School Entrance Gate (2nd Roundabout)	5˚10'03.11" N 7˚42'26.69" E	33.99
5	BH 5 (Shallow Boring)	Threatened Portion at Hostel Area Mid Gully Site	5˚10'06.45" N 7˚42'18.77" E	54.39
6	BH 6 (Shallow Boring)	Eroded Portion behind the Hostel Block (Circular Erosion Portion)	5˚10'05.17" N 7˚42'16.38" E	23.06

III. SUBSURFACE EXPLORATIONS

The subsurface exploration program at the project site comprised drilling of borings with the aid of percussion rig to a depth of 10.00m and 3.00m within the project site. Sampling was done at depth intervals of 1.00 meter each. A field log was prepared for each boring. Each log-contained information concerning the boring method, samples, attempted and recovered, indications of the presence of various materials such as silt, clay, gravel or sand and observations of ground water. It also contained an interpretation of subsurface conditions between samples. Therefore, these logs included both factual and interpretive information.

IV. SAMPLINGS

Six (6) borings were drilled. Soil samples were obtained at selected intervals in the soil test borings. Undisturbed soil samples were obtained, generally in accordance with ASTM D-1587 (Thin-Walled Tube Sampling of Soils) using a standard split-spoon sampler. A split-spoon sampler is a 50-mm outside diameter tube that is driven into the soil to be sampled that can be split opened lengthwise for easy removal and visual inspection of the soil obtained. Disturbed soil samples were obtained generally in accordance with ASTM D-1586 (Penetration Test and Split-Barrel Sampling of Soils). All samples were identified according to project number, boring number and depth, encased in polyethylene plastic wrapping to protect against moisture loss, and transported to Civil Engineering Department's laboratory in special containers. The soil samples were photographed, wrapped up in transparent membrane and stored in specially constructed wooden boxes according to their depths.

V. FIELD SPT-N VALUES

During the sampling procedures, standard penetration tests were performed in the borings in conjunction with the split-barrel sampling. The standard penetration value (N) is defined as the number of blows of a 18kg hammer, falling 760mm, required to advance the split-spoon sampler 300mm into the soil (ASTM D-1585). The sampler is lowered to the bottom of the drill hole and the number of blows recorded for each of the three successive increments of 150mm penetration. The "N" value is obtained by adding the second and third incremental numbers. The results of the standard penetration test indicate the relative density and comparative consistency of the soils, and thereby provide a basis for estimating the relative strength and compressibility of the soil profile components. The field sounding in terms of conventional standard penetration tests (SPT) carried out on the subsurface materials at the project site are shown graphically in the deep boring logs 1 and 2 in Fig. 1.

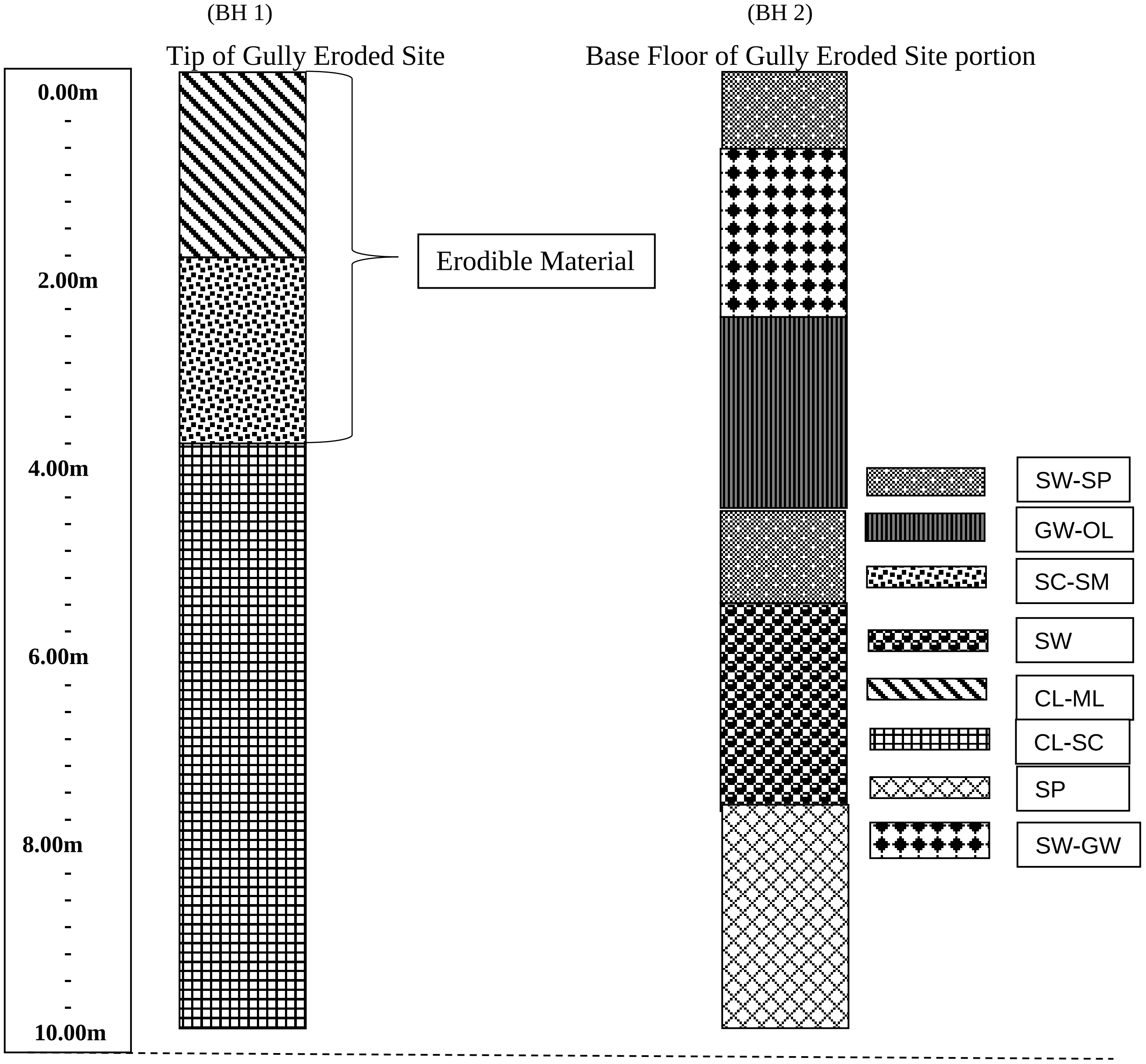

Figure1: Deep boring log for subsoil profile at tip and base floor of gully, Gorreti site, Ikot Ekpene.

VI. LABORATORY TESTS

The following laboratory tests were carried out on selected samples recovered from the borings at the project site.

A. Grain Size Analysis

Grain size distribution of soil particles involved both dry sieving and wet hydrometer analysis on the field obtained samples. Results of the grain size analysis are presented in Table 2.

B. Consistency of the Soil Samples.

The consistency of the soils at the project site was studied by evaluating the Atterberg limits which comprise liquid limits, plastic limits and plasticity indices. Also measured were natural moisture contents [NMC] and the liquidity indices of the soil samples. The liquid limit was determined in accordance with the recommended tests ASTM D423 and AASHTO T89 and the results are presented in Tables 2,3 and 4 for borehole numbers 1, 2 and 3 to 6 respectively. Plasticity indices are by definition the arithmetic differences between liquid limits and plastic limits, details of which are contained in the tests conducted in accordance with ASTM D424 and AASHTO T91. These indices indicate the range in moisture contents at which soils are in plastic conditions. The plasticity indices for the soils from the project site are also contained in Tables 2, 3 and 4 for boring numbers 1, 2 and 3 to 6 respectively. The natural moisture contents of the soil samples were determined in accordance with recommended standards and expressed as percentages of oven-dry weights of soils. Values of natural moisture contents for the soils at the project site are similarly presented in Tables 2, 3 and 4 to represent boring numbers 1, 2 and 3 to 6 respectively.

C. California Bearing Ratio (CBR)

The CBR test [as it is commonly known] involves the determination of the load-deformation curve of the soil in the laboratory using the standard CBR testing equipment. It was originally developed by the California Division of Highways prior to World War 11 and was used in the design of some highway pavements. This test has now been modified and is standardized under the AASHTO designation of T193. The essential procedures are as follows:

Disturbed samples of the selected soil material are compacted with standard rammer at different moisture contents in molds of 152mm internal diameter and 127mm height with a detachable base collar 50mm high using the standard AASHTO compacting method. The curve of dry density versus moisture content is then plotted. The sample having the highest dry density is selected for the CBR test. The selected compacted sample, still in the mold is immersed in water for four days to obtain a saturation condition similar to what may occur in the field. During this period the sample is loaded with a surcharge, usually 6.9kg. or greater that simulates the estimated weight of pavement material the soil will support. Any expansion of the soil sample due to soaking is measured. The sample is then removed from the water and allowed to drain for about fifteen minutes. The sample, still carrying the surcharge weight, is then subjected to penetration by the piston of the standard CBR equipment. The loads that cause different penetrations are recorded [in kN] and a load – penetration curve is drawn. The CBR is then determined as:

$$\text{CBR }(\%) = \frac{\text{Unit load for piston penetration in specimen } \left[\frac{\text{kN}}{\text{m2}}\right]}{\text{Unit load for piston penetration in standard crushed rock}} \text{x } 100 \quad (1)$$

From the curve, the corrected loads to produce a penetration of 2.5mm and 5.0mm are read off and expressed as percentages of the standard loads for crushed rocks of 13.24kN and 19.96kN respectively.

Equations 2.4 and 2.5 show that the CBR gives the relative strength of a soil with respect to crushed rock, which is considered an excellent coarse base material. The main criticism of the CBR test is that it does not correctly simulate the shearing forces imposed on sub-base and sub-grade materials as they support highway pavement. Results of these tests are presented on Table 4.

D. Unconsolidated – Undrained Triaxial Tests

Laboratory tests carried out to evaluate the shear strength of project site soils included the Unconsolidated-Undrained (U-U) triaxial test. For the U-U test, the saturated specimens were subjected to a confining fluid pressure in a triaxial chamber. Once the specimen was inside the triaxial cell, the cell pressure was increased to a predetermined value by rotating the knob of the constant pressure unit, and the specimen was brought to failure by increasing the vertical stress by applying a constant rate of axial strain. Since saturation and consolidation did not exist in this method, original structure and water content of sample was untouched. Pore and back pressures were not measured during this test and therefore the results can only be interpreted in terms of total stress over a confinement pressure (stress). Test results are presented in Tables 2 and 3

E. Standard Compaction Test

The modified AASHTO' compaction (T180) and the West Africa Standard (WAS) compaction were applied in the compaction experiments. The soil was compacted in the Proctor mold, using 25 blows from a 4.5 kg hammer dropping through a distance of 450mm on each of five equal layers. The optimum moisture content and the maximum dry density were found by a series of determinations of dry unit weight and the corresponding moisture content. Results obtained are recorded on Table 4.

F. Oedometer Consolidation Tests

Oedometer tests are designed to simulate the one-dimensional deformation and drainage conditions that soils experience in the field. The soil sample in an oedometer test is typically a circular disc of diameter-to-height ratio of about 3. The sample is held in a rigid confining ring, which prevents lateral displacement of the soil sample, but allows the sample to swell or compress vertically in response to changes in applied load. Known vertical stresses are applied to the top and bottom faces of the sample, typically using free weights and a lever arm. The applied vertical stress is varied and the change of the thickness of the sample is measured. One-dimensional oedometer consolidation tests were carried out over a pressure range of between 25.00 and 400.00 kPa on the cohesive soil samples from the project site. Values of coefficient of consolidation (C_v) and coefficient of volume compressibility (M_V) obtained from the tests are presented in Tables 2 and 3.

VII. Presentation of Tests' Results

TABLE 2: SUMMARY OF GEOTECHNICAL PROPERTIES OF SUBSOILS AT GORETTI SITE IKOT EKPENE, AKWA IBOM STATE (DEEP BORING NO. 1)

	Soil Type	**Sam No.**	**Depth (m)**	**USCS**	**Soil Consistency**			**Sat. Unit Wt. KN/m^3**	**U – U Triaxial Tests**		**Oedometer Consolidation Tests**				**Sound-ings**	**Grain Size Distribution Patterns**		
					wn (%)	LL (%)	PI (%)		ϕu (°)	C_u (kPa	M_v (m^2 / MN) x10^{-4} 50.0 KPa	M_v 400 kPa	C_v (m^2 / yr) 50.0 kPa	C_v 400 kPa	SPT (N)	2.00 mm	0.425 mm	0.075 mm
BH No. 1	Brownish Clayey Silty Sands (CL-ML)	1/1 1/2	1.00 2.00	CL-ML	42.4 39.5	35.6 33.4	9.7 9.2	1780 1780	8 8	38.2 41.2	0.49 0.51	0.62 0.75	0.79 0.83	0.90 0.95	8	99.7 98.8	75.0 72.0	38.6 37.6
	Brownish Silty Clayey Sands (SC-SM)	1/3	3.00	SC-SM	33.1	25.6	7.5	1840	12	34.6	0.32	0.45	0.65	0.76	9	97.8	67.6	29.0
	Red Brownish Lateritic Silty Sandy Clay (CL-SC)	1/4 1/5 1/6 1/7 1/8 1/9 1/10	4.00 5.00 6.00 7.00 8.00 9.00 10.00	CL-SC	37.2 - - 36.6 - - 35.7	32.2 - - 31.6 - - 30.6	10.4 - - 11.5 - - 12.7	1850 - - 1086 - - 1870	10 - - 12 - - 15	42.5 - - 48.2 - - 50.7	0.41 - - 0.43 - - 0.45	0.52 - - 0.55 - - 0.60	0.65 - - 0.69 - - 0.70	0.75 - - 0.81 - - 0.87	13 - - 17 - - -	98.6 - - 98.4 - - 97.6	71.1 - - 69.2 - - 68.2	35.7 - - 34.6 - - 33.8
Water Table (WT) - Not encountered at depth of investigation																		

TABLE 3: SUMMARY OF GEOTECHNICAL PROPERTIES OF SUBSOILS AT GORETTI SITE IKOT EKPENE, AKWA IBOM STATE (DEEP BORING NO. 2)

	Soil Type	**Sam No.**	**Depth (m)**	**USCS**	**Soil Consistency**			**Sat. Unit Wt. KN/m^3**	**U – U Triaxial Tests**		**Oedometer Consolidation Tests**				**Sound-ings**	**Grain Size Distribution Patterns**		
					wn (%)	LL (%)	PI (%)		ϕu (°)	C_u (kPa	M_v (m^2 / MN) x10^{-4} 50.0 KPa	M_v 400 kPa	C_v (m^2 / yr) 50.0 kPa	C_v 400 kPa	SPT (N)	2.00 mm	0.425 mm	0.075 mm
BH No.2	**Brownish Fine –medium Sands (SW-SP)**	2/1	1.00	**SW-SP**	12.2	NP	NP	2100	32	0.00	0.00	0.00	0.00	0.00	18	98.2	60.8	8.4
	Brownish Well-graded Sands & Gravels (SW-GW)	2/2 2/3	2.00 3.00	**SW-GW**	10.0 9.4	NP NP	NP NP	2250 2300	34 34	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	- 35	96.2 95.2	41.4 39.9	4.6 2.6
	Grayish Organic Gravelly Sands (GW-OL)	2/4 2/5	4.00 5.00	**GW-OL**	12.7 12.5	NP NP	NP NP	2320 2320	36 36	21.4 22.0	0.10 0.20	0.25 0.30	0.35 0.36	0.38 0.40	- 45	93.5 92.5	47.4 45.9	12.6 12.0
	Greyish Fine-medium Sands (SW-SP)	2/6	6.00	**SW-SP**	12.2	NP	NP	2150	32	0.00	0.00	0.00	0.00	0.00	56	97.8	59.8	9.8
	Brownish Well-graded Sands (SW)	2/7 2/8	7.00 8.00	**SW**	12.2 12.0	NP NP	NP NP	2200 2220	32 32	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	- 59	95.0 96.2	48.1 49.2	6.2 4.7
	Light Brownish Poorly-graded Sands (SP)	2/9 2/10	9.00 10.00	**SP**	11.0 11.5	NP NP	NP NP	2150 2180	30 30	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	- 65	96.5 96.8	52.4 51.9	7.7 8.2
Water Table (WT) - Encountered at depth of 2.50m at time of investigation																		

TABLE 4: SUMMARY OF GEOTECHNICAL PROPERTIES OF SUBSOILS AT GORETTI SITE IKOT EKPENE, AKWA IBOM STATE (SHALLOW BORING NOS 3, 4, 5 AND 6)

BH no.	Approx. Co-ordinates	Depth (m)	Soil Type	USC Class	AASHTO	Soil Consistency			Standard Compaction Test		California Bearing Ratio	Grain Size Distribution Patterns		
						Wn (%)	LL (%)	PI (%)	MDD (g/cm^3)	OMC (%)	CBR (%)	2.00 mm	0.425 mm	0.075 mm
BH 3	5°10'00.89" N 7°42'22.28" E	0.20-0.60 0.70-1.40 1.50-2.00 2.10-3.00	Brownish Clayey Silty Sands (CL- SM) Brownish Clayey Silty Sands (CL- SM) Red Brownish Lateritic Clayey Sands (SC-SM) Red Brownish Lateritic Clayey Sands (SC-SM)	CL-SM CL-SM SC-SM SC-SM	A-2-7 A-2-7 A-2-5 A-2-5	44.1 43.1 40.2 39.2	41.4 41.2 39.0 37.0	11.6 10.7 9.8 9.6	1.84 1.85 1.87 1.87	14.5 14.5 14.2 13.8	10.8 11.2 11.5 12.5	98.5 98.3 98.3 98.3	84.8 84.6 76.7 76.7	35.4 33.3 34.8 33.7
BH 4	5°10'03.11" N 7°42'26.69" E	0.20-0.60 0.70-1.40 1.50-2.00 2.10-3.00	Brownish Clayey Silty Sands (CL- SM) Brownish Clayey Silty Sands (CL- SM) Red Brownish Lateritic Clayey Sands (SC-SM) Red Brownish Lateritic Clayey Sands (SC-SM)	CL-SM CL-SM SC-SM SC-SM	A-2-7 A-2-7 A-2-5 A-2-5	43.2 41.1 39.5 38.6	41.3 41.9 40.0 39.0	11.4 10.6 9.7 9.2	1.85 1.86 1.87 1.88	14.3 14.5 14.1 13.9	10.9 11.2 11.5 11.9	99.2 98.8 98.5 98.1	82.1 79.1 76.3 70.3	35.0 34.6 34.0 34.0
BH 5	5°10'06.45" N 7°42'18.77" E	0.20-0.60 0.70-1.40 1.50-2.00 2.10-3.00	Dark Brownish Organic Clayey Silt (OL-CL) Brownish Clayey Silty Sands (CL-SM) Red Brownish Lateritic Clayey Sands (SC-SM) Red Brownish Lateritic Clayey Sands (SC-SM)	OL-CL CL-SM SC-SM SC-SM	A-7 A-2-7 A-2-5 A-2-5	45.1 41.1 38.2 37.6	43.4 39.1 37.0 35.0	8.5 11.6 9.8 9.5	1.72 1.84 1.87 1.88	15.6 14.8 14.2 14.0	8.9 10.6 11.7 12.0	99.7 98.4 98.3 98.0	87.8 74.6 73.1 71.7	41.7 35.3 34.5 32.8
BH 6	5°10'05.17" N 7°42'16.38" E	0.20-0.60 0.70-1.40 1.50-2.00 2.10-3.00	Red Brownish Clayey Sandy Silt (ML-SM) Red Brownish Lateritic Clayey Sands (SC-SM) Red Brownish Lateritic Clayey Sands (SC-SM) Red Brownish Lateritic Clayey Sands (SC-SM)	ML-SM SC-SM SC-SM SC-SM	A-2-5 A-2-5 A-2-5 A-2-5	34.8 36.0 37.2 36.0	36.8 38.0 36.4 35.2	7.4 9.4 8.9 8.7	1.89 1.85 1.86 1.87	12.1 13.2 13.8 13.3	11.6 12.7 12.5 12.9	*98.5* *98.2* *98.1* *97.8*	*67.5* *72.5* *76.9* *78.9*	*29.5* *32.9* *34.3* *32.5*

Table 5: Drainage Characteristics of Soils at the Gully Erosion Site

Soil Type	Coefficient Of Permeability (K) Cm/Sec	Remarks
Red Brownish Lateritic Silty Sandy Clay (CL-SC)	1.72×10^{-8} to 1.60×10^{-8}	Moderately permeable but friable when dry; high water absorbency. high compressibility.
Brownish Clayey Silty Sands (CL-SM)	1.20×10^{-7} to 1.34×10^{-7}	Moderately high permeability, high compressibility.
Brownish Silty Clayey Sands (SC-SM)	1.85×10^{-8} to 1.34×10^{-7}	Moderately high permeability, high compressibility.
Brownish Well-graded Sands & Gravels (SW-GW)	1.45×10^{-2} to 1.95×10^{-2}	Very highly permeable, incompressible
Brownish Well-graded Sands (SW)	1.20×10^{-3} to 1.39×10^{-2}	Highly permeable, incompressible
Light Brownish Poorly-graded Sands (SP)	1.95×10^{-3} to 1.70×10^{-3}	Highly permeable, incompressible
Greyish Fine-medium Sands (SW-SP)	1.45×10^{-4} to 1.90×10^{-3}	Highly permeable, incompressible
Grayish Organic Gravelly Sands (GW-OL)	1.85×10^{-4} to 1.70×10^{-3}	Moderately high permeability, very low compressibility.
Dark Brownish Organic Clayey Silt (OL-CL)	1.45×10^{-4} to 1.95×10^{-3}	Moderately high permeability, very high compressibility.
Red Brownish Clayey Sandy Silt (ML-SM)	1.20×10^{-9} to 1.34×10^{-8}	Moderately high permeability, low compressibility.

VIII. Analysis of Soil Bearing Capacity at Gully Location Based on SPT Method

The allowable net soil pressure for the design of a foundation based on the SPT field data may with sufficient accuracy be taken as:

$$Q_a = 1/FS \{0.22N\ (0.1073)\ (1000)\} KN/m^2 \quad (2)$$

Where: N = SPT value (corrected for water table effects)

Q_a = Allowable net soil bearing capacity KN/m^2
FS = Factor of safety (assumed to be 2.5)

Based on SPT (N) values obtained from both boreholes 1 and 2, the allowable bearing capacities at the various depths are presented in Table 6.

Table 6: Encountered Soil Profile and SPT Bearing Capacity

Boring Position	Soil Description /USCS Class	SPT (N) Value	Depth Encountered (m)	Allowable Bearing Capacities KN/m^2 (KPa)
BH 1 Tip of Gully Erosion (Deep Boring)	Brownish Clayey Silty Sands (CL-ML) Brownish Silty Clayey Sands (SC-SM) Red Brownish Lateritic Silty Sandy Clay (CL-SC)	8 9 13-17	0.00 - 2.00 2.00 - 3.00 4.00 -10.00	75.53 84. 97 122.74- 160.51
BH 2 Base floor of Gully Erosion (Deep Boring)	Brownish Fine –medium Sands (SW-SP) Brownish Well-Graded Sands & Gravels (SW-GW) Grayish Organic Gravelly Sands (GW-OL) Greyish Fine-medium Sands (SW-SP) Brownish Well-Graded Sands (SW) Light Brownish Poorly-graded Sands (SP)	18 35 45 56 59 65	0.00-1.50 2.00-3.00 4.00-5.00 6.00–7.00 7.00–8.00 9.00-10.00	169.95 330.47 424.89 528.75 557.07 613.73

IX. DISCUSSION OF RESULTS OF FINDINGS

A summary of soil characteristics from borehole No.1 shows a brownish lateritic silty sand (CL-SC) as the major stratification from 4 to 10 meters below the ground surface. The saturated unit weight varied from 1850kg/m^3 to 1870kg/m^3. The soil friction angle ranged from 10^o to 15^o. Soil cohesion (C) varied from 42.5kPa to 50.4kPa. Coefficient of volume compressibility (M_v) data ranged from 0.52m^2/MNx10^{-4} to 0.60m^2/MNx10^{-4} at 400kPa of increased pressure. The coefficient of consolidation (C_v) ranged from 0.75m^2/yr to 0.87m^2/yr under same 400kPa of increased pressure. The standard penetration test sounding varied from 56 to 65 within the 4m to 10m depth. A distinctive feature is that no ground water was encountered in this borehole even at 10 meters depth.

Within borehole No. 2 the soil stratification assumed a diverse characteristic. From 4 meters to 10 meters below the ground surface, the soil saturation value ranged from 2320 kN/m^3 to 2180 kN/m^3. The soil friction angle varied from 36^o to 30^o. The California bearing ratio and cohesion were zero, coefficient of volume compressibility (M_v) was zero, coefficient of consolidation (C_v) was equally zero. This was an indication of soil devoid of plasticity and fully saturated.

The major data derived from shallow boreholes 3 to 6 were the grain size distribution, consistency, moisture content, compaction and California bearing ratio values. The plasticity index (PI) values varied from 11.6 down to 9.6, 11.4 down to 9.2, 11.4 down to 9.2, 9.4 down to 8.7 in boreholes 3, 4, 5 and 6 respectively. The maximum dry density (MDD) values ranged from 1840kg/m^3 to 1890kg/m^3. The optimum moisture content (OMC) values ranged from 13.3% to 15.6% and the CBR values varied from 10.8% to 12.9% within the four boreholes.

The coefficient of permeability (k) varied from 1.45x10^{-2} (very high) to 1.20x10^{-9}(moderate) permeability.

Based on SPT-N method of analysis, the allowable bearing capacity in borehole No.1 at the tip of gully ranged from 75.53kPa to 160.51kPa. Similar exercise on borehole No.2 revealed allowable bearing capacity values ranging from 169.95kPa to 613.73kPa. By implication the consolidation and settlement characteristic is greater at borehole No.2.

X. Conclusions

The tip of gully (BH1) revealed soils' stratification with relatively low allowable bearing capacity of 75.53kPa. This is highly prone to erodibility. A cantilevered retaining structure and gabion wire mesh stacking is a viable option to curtail the erodibility of the location. From 4.0 meter to 10.0-meter depth, there is considerable improvement in the allowable bearing capacity. A trapezoidal concrete drain can thereafter be constructed but the adjoining soil / concrete surfaces should be protected with geo-textile membrane to provide both drainage and protection against water scour and gullying processes.

The slopes of the embankments should be grassed with fast growing weeds to stabilize the embankments and therefore prevent failures. The base floor (BH2) soil characteristics revealed comparatively high allowable bearing capacity values of 169.95kPa to 613.73kPa, an indication of very low erodibility. A bell mouth discharge outlet concrete drain with designed gradient will ensure a laminar discharge without scouring.

Finally, information and data from the shallow borings (BH3) to (BH6) will aid decision on choice of base and subbase materials for access road construction to the Goretti site.

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