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Utilization of Revetments in Gully Erosion Control in the Nnewi Drainage Area of Anambra State, Nigeria

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ABSTRACT

This paper addresses the 'Utilization of Revetments as a Control Measure in curbing the Gully Erosion Problems of the Nnewi Drainage Area of Anambra State, Nigeria'. Representative fifteen (15) soil samples were collected from different depths/levels of gully sites and their geotechnical properties/characteristics measured and analyzed in laboratories. Results of the laboratory measurements indicate that the soils at the gully sites are predominantly sands (84.0%-90.0%; mean: 86.0%) and silt/clay (fines: 2.0%-11.0%; mean: 5.0%) fractions. The liquid limit (LL) ranges from 20.5% to 26.4%; with a mean of 19.5%; while the plasticity index (PI) ranges from 7.0% to 11.4%; with a mean of 7.32%. The maximum dry density (MDD) values range from 1.80mg/m^3 to 1.92mg/m^3; with a mean of 1.88mg/m^3. The optimum moisture content (OMC) values range from 15.0% to 16.8%; with a mean of 15.8%; while the shear strength values comprising cohesion (c) that ranges from 2.OKN/m^2 to 3.OKN/m^2; with a mean of 2.5KN/m^2; and angle of internal friction ( ) that ranges from 25.0° to 28.0°; with a mean of 26.0°. With the scientific analysis of results of the area's soils, typical revetment design was made. Through the analyses, it was established that revetments possess the engineering characteristics and potentials that cannot only check, reduce, or control erosion, but can also be applied in the reclamation of devastated lands.

Keywords: *Revetment, Gully, Erosion, Drainage, Geotechnical, Topographical, Reclamation, Friction, Stability.*

Introduction

The Study Area

The study area situates in-between latitude $5^0\ 15' - 5^0\ 55'$ and longitude $7^0\ 15' - 6^0\ 55'$ in the Anambra basin (Egboka, Chigbo and Okudo, 1993). It covers an area of about 72km^2 and is one of the major environmentally developed geographical areas in the Anambra South Senatorial zone of Anambra State of Nigeria. Anambra State is one of the 36 states in the federation of Nigeria and one of five states in the South-east geo-political zone of the country. The area for this study covers the boundaries of the Ekwusigo, Idemili, Nnewi North and Nnewi South local governments, with approximately one-third of this area fully built (Figure 1).

The soils of the Nnewi drainage area consist of sandy, lateritic and alluvial. In some areas, they are porous, non-resistant and non-load bearing. These soil conditions, combined with the steep slopes of the valleys and rivers of Ulasi and Ofala have been responsible for the excessive and persistent soil erosions experienced in the sub-region. The soil problems of the study area include the variability of the soils from strata to strata and the hydrological characteristics of the area. Each stratum is about 600mm in depth. In some parts of the research axis, and in some cases, 'expansive soils' are buried under layers of top soils or dense vegetation and cannot be indentified at the surface (Onyeka, 2010). The topographical features in the study area are uplands, lowlands, stream channels and gullies of variable dimensions scattered in the drainage area. These landforms vary in elevation from 65m to 212m above sea level.

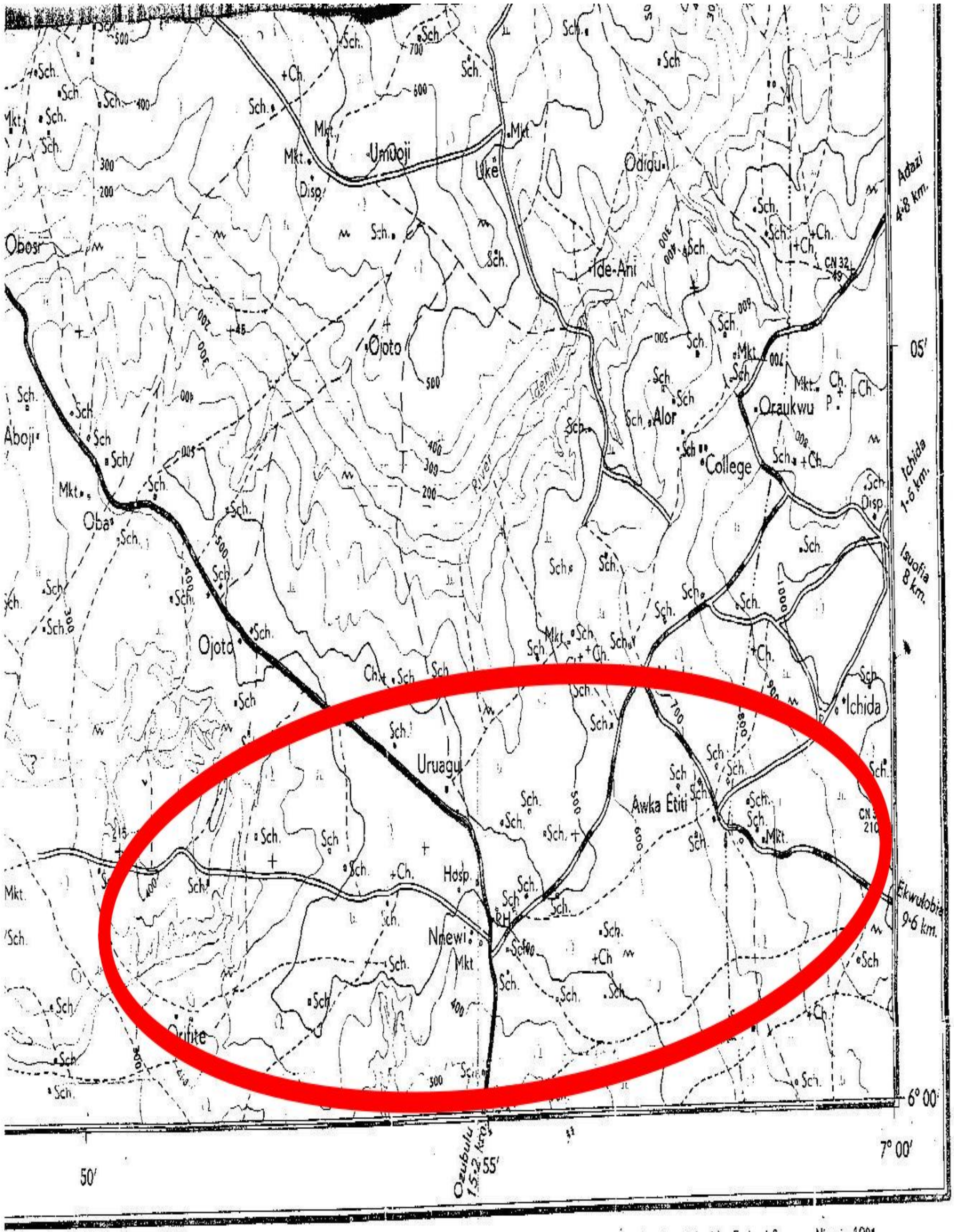

Fig. 1. Map of Part of Anambra State of Nigeria Epicting the Research Area

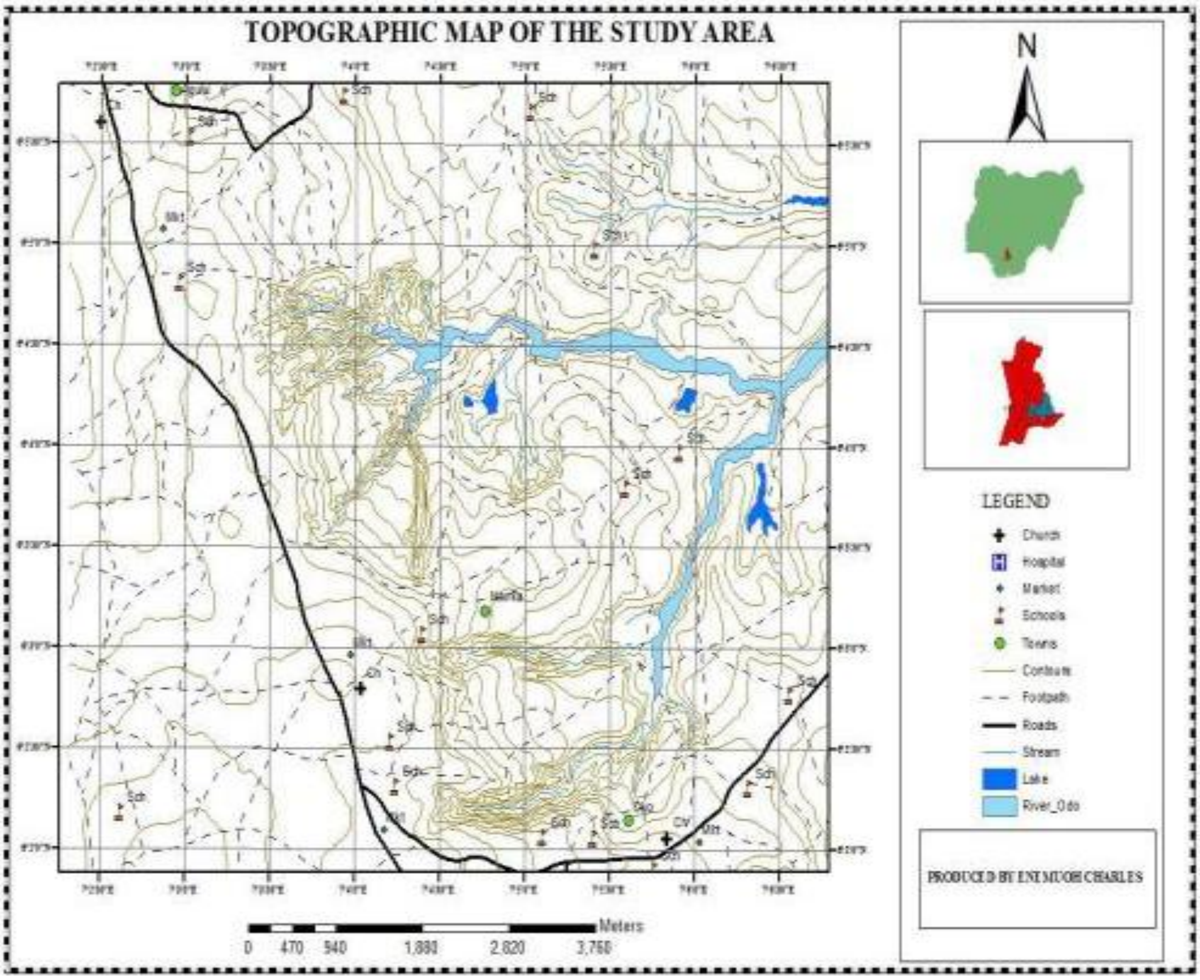

Fig.2. Overlay Map Of The Study Area Showing The Following Features: Streams, Lake, Rivers Ulasi And Ofala, Markets, Schools, Towns, Footpaths And Roads.

Revetments

A revetment is a retaining wall or facing of masonry or other material, supporting or protecting a rampart, wall or an embarkment. It could also be a barricade of earth or sandbags set up to provide protection from blast (Thorndike, 1992). Revetments are classified as either conventional retaining walls or mechanically stabilized earth walls (Federal Highway Authority, 1989). Revetments may be constructed as sloping structures and are very often constructed as permeable structures using natural stones or concrete blocks, thereby enhancing wave energy absorption and minimising reflection and wave run-up. Revetments can consist of different kinds of concrete slabs, some of them permeable and interlocking. In this way their functionality is increased in terms of absorption and strength. An example of a permeable and interlocking concrete slap is the so-called Flex Slap. It is important to realize that revetments are no solution for structural erosion problems.

The main components of reinforced revetments are (Jones, 1995):

1) Backfill, which is granular soil
2) Reinforcing strips, which are thin, wide strips placed at regular intervals. These may be geotextile, geogrid, metal strips, bars, or welded wire mats.
3) A cover on the front face, which is referred to as the skin.

The skin can be constructed with sections of relatively flexible thin material (Casagrande, 1973).

Stabilization of the Gully Faces in the Study Area using Revetments

The stabilization process might come about through the utilization of revetments, geogrids or geonets, or, even soil nailing (Ingold, 1995).The solution normally suggested by structural engineers is to backfill the gullies, but, this is just postponing the problem for a later date and to the future generation as the process will recommence if adequate remedial measures are not taken.

Typical Revetments Construction

Wooden Revetment

Fig. 3. Wooden Revetment

Revetment along a River

Fig. 4. Revetment along a River

Gabon Mattress Revetment at Foot of Dike

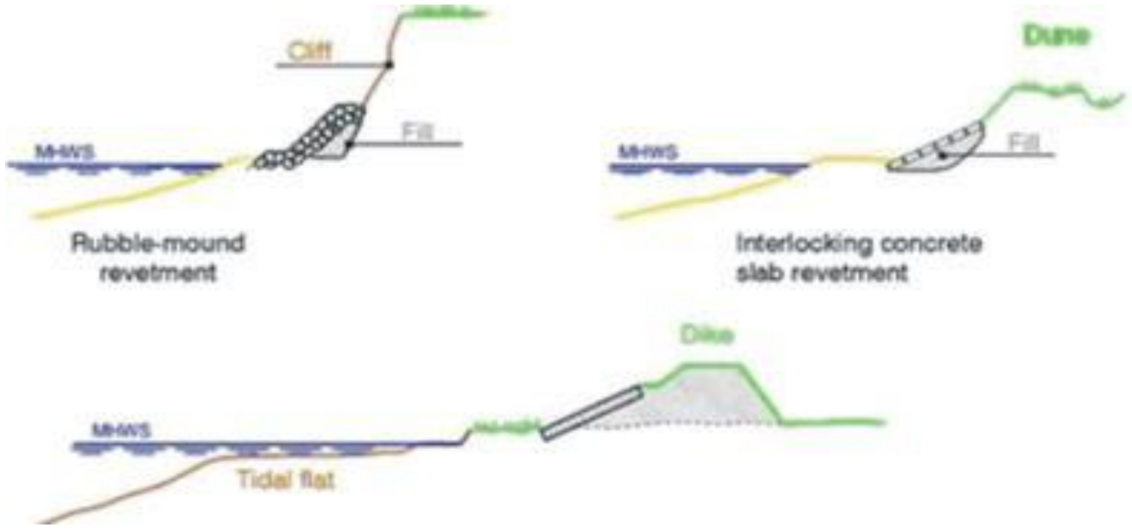

Fig.5. Gabion Mattress Revetment at Foot of Dike

Asphalt and Sandbag Revetment with a Geotextile Fitter

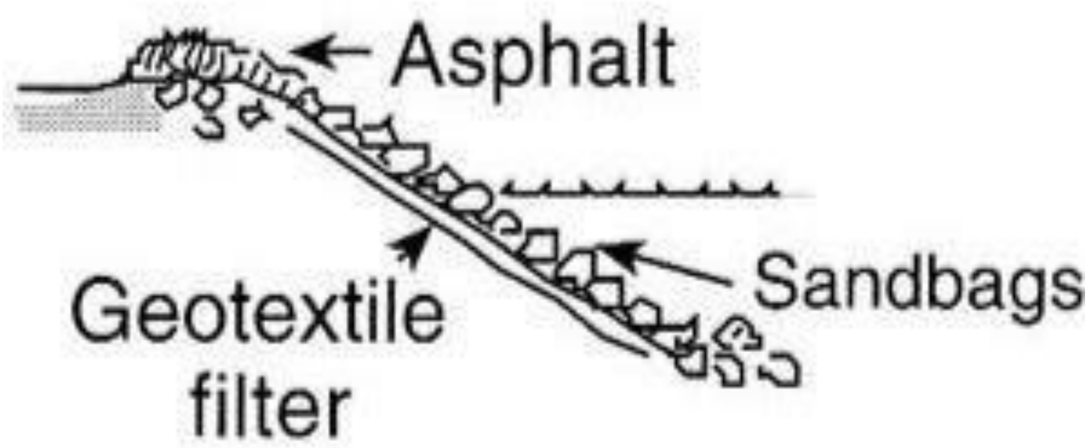

Fig.6. Asphalt and Sandbag Revetment with a Geotextile Filter

Materials and Methods

Sample Collection

Soil investigation which comprised field study and laboratory analyses was undertaken. The field investigation for soil data collection involved sampling and measurement in the study area (Fig.1 and table 1). Soil samples were collected from the gullies' walls at various depths ranging from 3.0 meters to 16.0 meters (Plates 1 & 2).The techniques for sample collection followed those of Spangler and Handy (1973). Five (5) gully wall Profiles in five (5) gully locations were examined and a total of fifteen (15) soil samples were collected and packaged in polythene bags for laboratory analysis. The vertical soil sampling on the gully walls was to ascertain changes in the soils' properties.

Laboratory Tests

A series of geotechnical tests including Particle-size analysis, Atterberg limits, and Compaction and Shear strength tests were performed on the soil samples in accordance with the procedures specified by the American Society for Testing Materials (ASTM) and the British Standard Methods for Testing Soils for Civil Engineering Purposes (BS, 1377-1990).The laboratory tests were conducted to determine the soils' index properties.

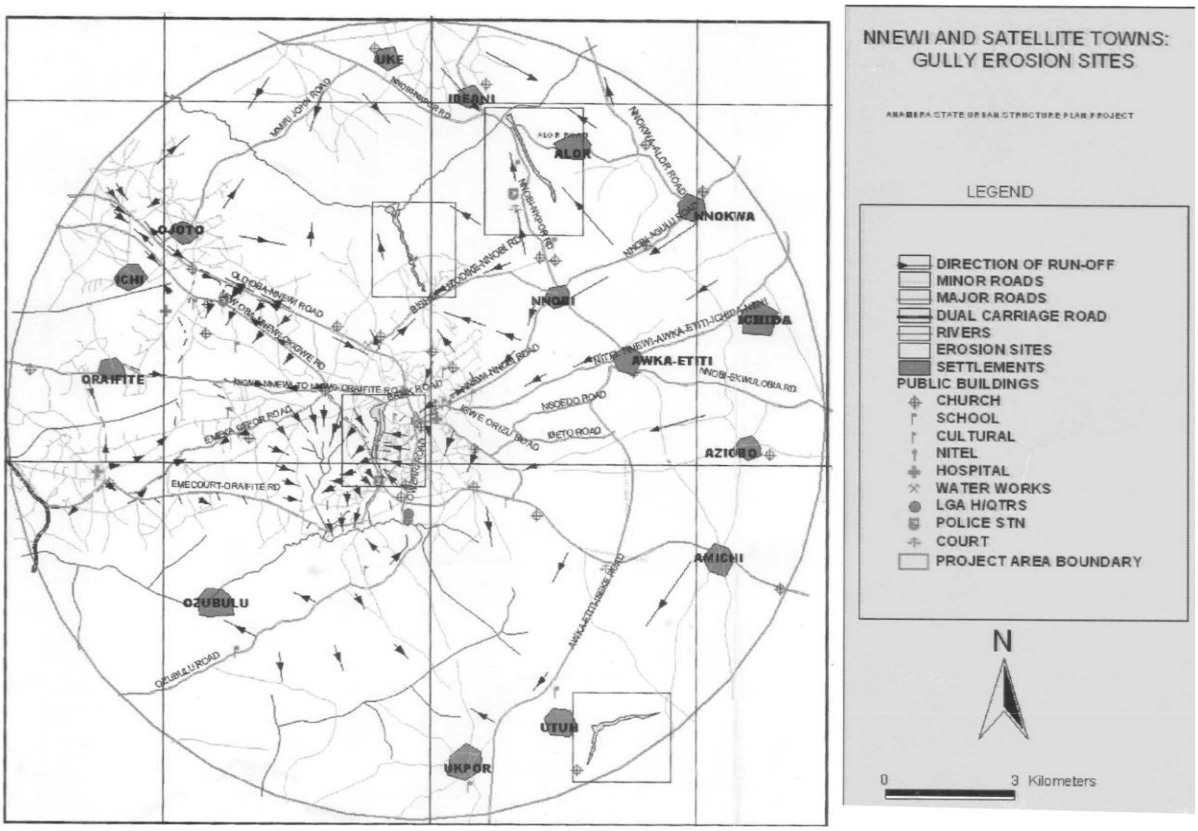

Fig.7. Gully Erosion Sites in the Study Area

Plate 1: *An erosion site undergoing control with revetment construction in the Nnewi drainage area. Source: The researcher, February, 2018.*

Plate 2: An Erosion Site Undergoing Control with Revetment Construction in Awka-Etiti (In the Nnewi Drainage Area).
Source: The Researcher, February, 2018.

RESULTS AND ANALYSIS OF RESULTS

Table 1: Summary of Geotechnical Properties of Soil Samples in the Study Area

Parameters	Parent Rocks/location														
	Ogwashi-Asaba formation/Eocene Ulasi sands														
	Nnewi			Ukpor			Ozubulu			Ichida			Utuh		
Depth(m)	3	8	16	3	8	16	3	8	16	3	8	16	3	8	16
LL(%)	25.2	25.1	25.0	26.4	23.8	22.2	23.6	20.8	20.5	26.4	22.5	20.5	26.4	25.2	22.0
PL(%)	22.4	21.0	18.0	15.0	14.6	14.2	14.1	12.1	12.1	15.0	12.1	11.5	15.0	14.2	12.8
PI(%)	9.8	9.0	7.0	11.4	9.2	7.0	9.5	8.7	8.4	11.4	10.4	7.0	11.4	8.4	7.0
Gravel (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sand (%)	88.0	90.0	92.0	89.0	90.0	90.0	84.0	86.0	90.0	88.0	89.0	90.0	84.0	86.0	90.0
Fines(%)	3.0	3.0	2.0	11.0	6.0	5.0	6.0	5.0	4.0	8.0	4.0	3.0	7.0	7.0	6.4
Dry Density (Mg/m^3)	1.80	1.72	1.60	1.70	1.62	1.50	1.52	1.42	1.40	1.80	1.76	1.66	1.76	1.70	1.62
Max. dry density (Mg/m^3)	1.94	1.86	1.86	1.89	1.88	1.87	1.92	1.92	1.89	1.90	1.89	1.87	1.90	1.87	1.80
OMC(%)	16.4	15.5	15.0	16.0	15.9	15.0	16.2	15.0	15.1	16.2	16.1	15.6	16.1	16.0	15.5
MC (%)	13.3	11.8	11.0	12.8	11.0	10.5	10.2	8.2	6.8	8.6	7.2	6.2	8.2	6.0	5.2
Cohesion (KN/M^2)	2.0	2.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	2.0	2.0
AIF (degrees)	25	26	26	26	28	28	25	25	28	26	26	28	25	26	28

* *S. Unit 1. $<$3.0m below ground surface, S. Unit 2. $>$3.0m and $<$16.0m. S. Unit 3. $>$16.0m.*

Revetment Design Utilizing the Research Area's Site Soil Analyses Results.

Design of a Revetment (Retaining Wall) on an Erosion Site in Ukpor (in the Nnewi Drainage Area) using Geotextile Reinforcement.

1) The backfill is a granular soil
2) The step-by-step design procedure is based on the recommendations of Berg et al. (1986) and Koerner (1990).

Internal Stability

1) The active pressure distribution on the wall is determined from $\sigma_a = K_a\sigma_v = k_a\gamma_1 z$

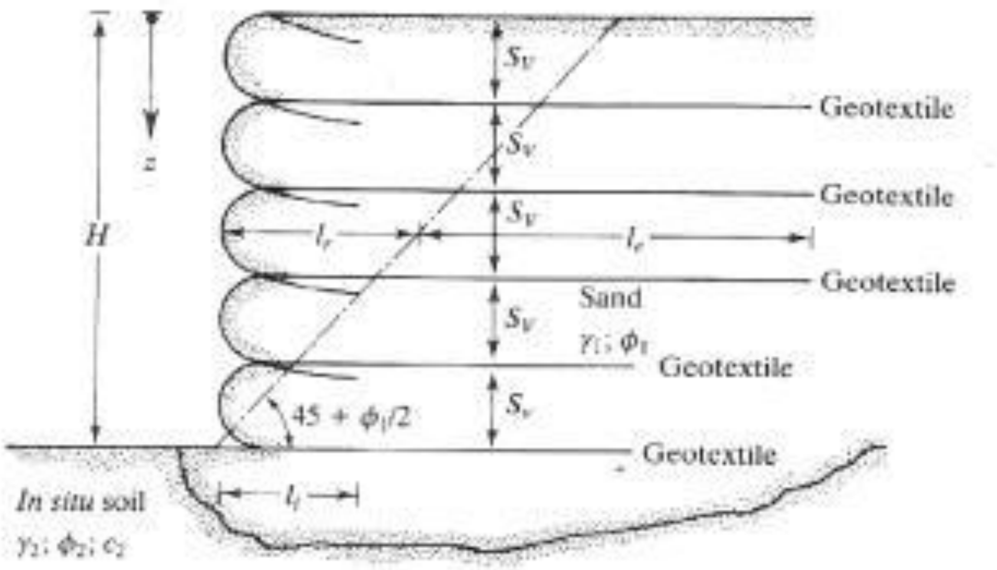

Fig. 8. Revetment (Retaining Wall) With Geotextile Reinforcement

Where = Rankine earth pressure coefficient = tan2 (45 – Ø1/2)
γ1 = Unit weight of the granular backfill as measured in the laboratory
Ø1 = Friction angle of the granular backfill.

2) A geotextile fabric that has an allowable strength of σ_GKN/m is selected.
3) The vertical spacing of the layers at any depth z is determined from the equation.

$$S_v = \frac{\sigma_G}{\sigma_a\, FS_{(B)}} = \frac{\sigma_G}{(\gamma_1 zK_a)\,[FS_{(B)}]}$$

$$\text{where } FS_{(B)} = \frac{\text{yield or breaking strength of each tie}}{\text{maximum tie force in any tie}}$$

$$= \frac{\text{wtf}_y}{\sigma_a\, s_V s_H}$$

The magnitude of ( )is generally 1.3 - 1.5

4) The length of each layer of geotextile is determined from the equation L = lr + le

$$\text{where } l_r = \frac{H-Z}{\tan\left[45+\frac{\emptyset_1}{2}\right]}$$

and

$$l_e = \frac{S_v\sigma_a[FS_{(P)}]}{2\sigma_v \tan\emptyset_F}$$

$$\sigma_a = \gamma_1 z K_a$$

$$\sigma_v = \gamma_1 z$$

$$FS_{(P)} = 1.3 \text{ to } 1.5$$

$$\emptyset_F = \text{friction angle at geotextile – soil interface}$$

$$\approx \tfrac{2}{3}\emptyset_1$$

Type			$\emptyset_F/\emptyset_1$
Woven	–	monofilament/concrete sand	0.87
Woven	–	silt film/concrete sand	0.8
Woven	–	silt film/rounded sand	0.86
Woven	–	silt film / silty sand	0.92
Nonwoven	–	melt-bonded/concrete sand	0.87
Nonwoven	–	needle-punched/concrete sand	1.0
Nonwoven	–	needle-punched/rounded sand	0.93
Non-woven	-	Needle-punched/silty sand	0.91

The lap length, *l1* is determined from the equation:

$$l_1 = \frac{S_v\sigma_a FS_{(P)}}{4\sigma_v \tan\emptyset_F}$$

The minimum lap length should be 1m.

External Stability

5) The factors of safety against overturning, sliding, and bearing capacity failure are checked.

The following data were measured /obtained at the site:

Height of the geotextile-reinforced revetment (retaining wall) to be designed, according to the height of the gully face that is needed to be supported = 4.88m.

The granular soil has the following characteristics:
γ1 = 17.29KN/m3 = 17290N/m3
Ø1 = 360

For the geotextile with σ_G = 14,010N/m.
To design the revetment reinforced with geotextile, it is required to determine , *L* and *l1*

Designing of the Retaining wall:

$$K_a = \tan^2\left(45 - \frac{\emptyset_1}{2}\right) = 0.26$$

Determination of :
To find , we make a few trials
From the equation,

$$S_v = \frac{\sigma_G}{(\gamma_1 zK_a)\,[FS_{(B)}]}$$

With $FS_{(B)}$ = 1.5 at z = 2.4m,

$$S_v = \frac{14010\text{N/m}}{17290\text{N/m}^3\,(2.44\text{m})(0.26[1.5]} = 0.85\text{m}$$

At z = 3.66m,

$$S_v = \frac{14010\text{N/m}}{17290\text{N/m}^3\,(3.66\text{m})(0.26)[1.5]} = 0.57\text{m}$$

At z = 4.88m,

$$S_v = \frac{14010\text{N/m}}{17290\text{N/m}^3\,(4.88\text{m})(0.26)[1.5]} = 0.43\text{m}$$

So, we use = 0.50m for z = 0 to z = 2.44m
and
= 0.40m for z > 2.44m
This is shown in the figure 9 below,

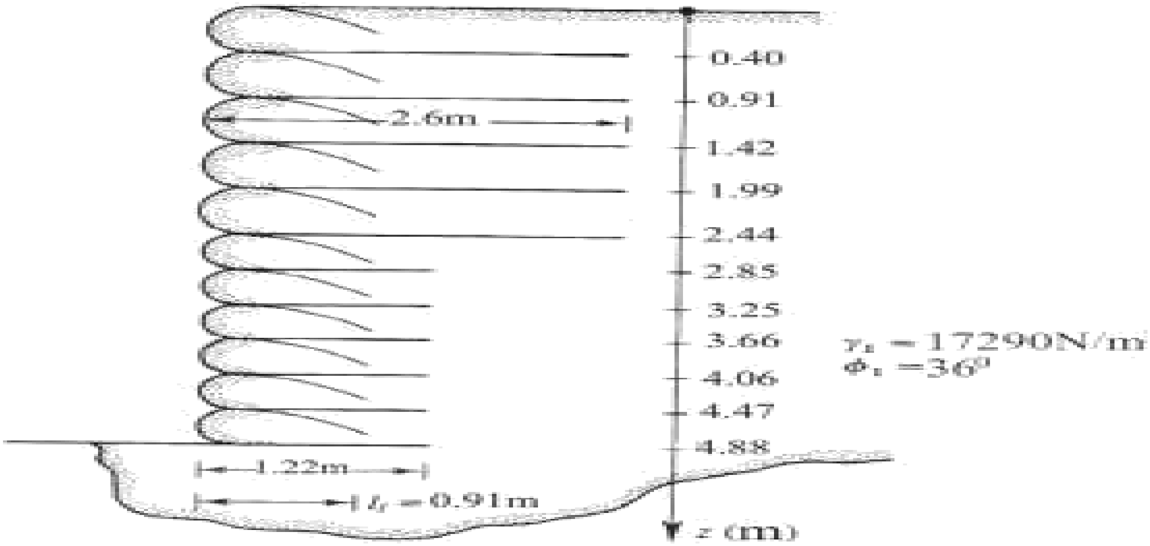

Fig. 9. Design Presentation of a Geotextile-Reinforced Revetment (Retaining Wall) 4.88m High.

CONCLUSION

The research area's erosion problem is a serious ecological hazard. Its main causes are high human activities combined with heavy rainfall and soils of high erodibility. Erosion control efforts in the area have, so far been uncoordinated and un-sustained. Analyses results show that revetments can be designed with high stability to resist forces and pressures from fluid flow and wind, which are main aggravators of erosion. With proper design, construction and positioning of revetments, they can be protected channels for flood plain courses. This enhances discharge of water in environmentally-good ways devoid of flooding and erosion. Revetments, when properly constructed, can also be useful in land reclamation if appropriate and tested backfill materials are employed. For erosion control, the stability and capacity of revetments in the absorption of forces and energy of wind, water and lateral earth pressures, which are erosion enhancing agents, make them suitable structures. Revetments can also be used in sedimentation management and control if they are constructed in conjunction with sediment control structures like silt fences and retarding structures (sedimentation weirs) to reduce degradation of erosion beds.

RECOMMENDATION

1) At the appropriate locations in the research area, revetments should be constructed to curb gully erosion initiation and expansion, serve as protected channels for floodplains, employed in land reclamation and in sedimentation management.
2) Hitherto, design and construction of revetments (retaining structures) with geotextile facings have been done in tshe research area without anchoring wire mesh to the facings. It is recommended that meshes be anchored on the faces of the gullies so as to keep the coatings on the walls' faces.
3) To be effective and economical, erosion control structures like revetments, should be designed into, and not added cosmetically after the execution of comprehensive erosion control projects.

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