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Shear Stress Impact on Coastal Water Defense Structures in Asaba River Niger Waterways

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Abstract:- This work serves as a useful tool for the design and redesign of new and existing coastal structures by water engineers in Coastal Engineering works. The Pin technique with relevant models was used in the actualization of the presence of erosion. Surface friction coefficient, wind speeds in the x and y directions, and water density were obtained and used in measuring shear stress in the x and y directions. This was used in understanding the force impact generated from both directions. The resultant values of 233.2047 and 306.8813 respectively were obtained. From the results obtained, it was concluded that shear stress impact was notably observed to be significant in wearing off the coastal structures.

Keywords*: Erosion Measurement methods; Water Erosion; Water Defense Wall.*

1. Introduction

Coastal water defense structures, including seawalls, breakwaters, levees, and revetments, play a critical role in protecting shorelines and coastal communities from the destructive forces of waves, tides, and storm surges (Okolotu and Oluka 2021a). These structures are designed to withstand a range of environmental forces, but one of the most influential factors affecting their integrity is shear stress. Shear stress, defined as the force per unit area exerted parallel to the plane of interest by fluid flow, significantly impacts the stability and durability of coastal defenses. Shear stress arises from the interaction between flowing water and the surface of defense structures (Okolotu, 2024). The magnitude of shear stress is influenced by factors such as water velocity, turbulence, wave action, and the structural properties of the defense mechanisms themselves. Over time, the continuous application of shear stress can lead to erosion, material fatigue, and structural weakening, which compromise the effectiveness of these protective barriers (Supli et al 2017). Understanding how shear stress impacts coastal defense structures is essential for designing resilient systems capable of withstanding long-term environmental pressures (Okolotu *et al*., 2024).

The impact of shear stress on coastal defense structures is multifaceted. It involves complex interactions between hydrodynamic forces, sediment transport, and the physical and mechanical properties of construction materials (Theofanis and Karambas, 2014). In coastal environments, shear stress contributes to the scouring of foundations, the displacement of protective materials, and the formation of cracks and fissures. These processes can accelerate the degradation of structures, increasing maintenance costs and the risk of catastrophic failures. Furthermore, climate change and rising sea levels exacerbate the effects of shear stress on coastal defenses (Okolotu *et al*., 2024). Increased frequency and intensity of storms, coupled with higher water levels, intensify the hydraulic forces exerted on these structures, demanding more robust and adaptive design solutions. As such, modern coastal engineering must incorporate advanced materials, innovative construction techniques, and comprehensive maintenance strategies to address the evolving challenges posed by shear stress (Theofanis and Karambas, 2014).

In the context of the Asaba River Niger Waterways, the impact of shear stress is further exacerbated by seasonal variations in water flow, sediment transport, and human activities such as dredging and construction. These factors collectively influence the hydraulic conditions and stress distribution along the waterway, necessitating a comprehensive assessment of shear stress dynamics to inform the design and reinforcement of coastal water defense structures. This introduction aims to set the stage for a detailed exploration of the mechanisms by which shear stress affects coastal defenses in the Asaba River Niger Waterways. It will examine the sources and magnitude of shear stress, the material and structural responses of defense mechanisms, and the implications for maintenance and policy planning.

The Asaba River Niger Waterways are vital for the economic and social activities of the region, supporting transportation, trade, and community livelihoods. However, the coastal water defense structures within these waterways, such as embankments, levees, and revetments, are increasingly subjected to the adverse effects of shear stress. Shear stress, the force per unit area exerted parallel to a plane by fluid flow, significantly impacts the stability and integrity of these protective structures. Despite their critical role in safeguarding the shoreline and preventing inland flooding, these coastal defenses face continuous degradation due to the persistent application of shear stress. Factors such as seasonal variations in river flow, sediment transport, and human activities like dredging and construction amplify the shear stress effects, leading to material erosion, structural displacement, and eventual failure. This degradation not only threatens the functionality of the defense structures but also poses significant risks to the safety and well-being of the surrounding communities.

The current engineering and maintenance practices in the Asaba River Niger Waterways have not adequately addressed the complexities and cumulative impacts of shear stress on coastal defenses. There is a lack of comprehensive data and analysis on the specific shear stress dynamics in this region, hindering the development of effective design and reinforcement strategies. Without targeted research and innovative solutions, the resilience of these structures will continue to diminish, exacerbating the vulnerability of the Asaba River Niger Waterways to environmental and anthropogenic pressures. Therefore, it is imperative to systematically investigate the shear stress impact on coastal water defense structures in the Asaba River Niger Waterways. This investigation should aim to quantify the shear stress levels, understand the mechanisms of structural degradation, and develop adaptive design and maintenance approaches. Addressing this problem will enhance the durability and reliability of coastal defenses, ensuring the long-term protection of the region's shoreline and communities against the dynamic forces of the river.

1.1 Water Defense Wall:

A water defense wall is a water-holding structure designed and built to protect its shore/coasts from the impact of the water body. The world population is on the increase even with a declining growth rate (Okolotu and Oluka 2021a; Okolotu G.I., 2024; Okolotu *et al*., 2024). Securing and conserving the coastal environment against erosion is vital for land availability for agricultural and other beneficial purposes. Measuring contributory factors that impact coastal structures is necessary for a proper understanding of coastal erosion processes. A typical defense wall is presented in Figure 2 (1) below;

Figure 1: Water Defense Wall

Water defense walls are bioengineering techniques deployable in retaining the supposed effect channeled towards coastal structures. Examples of defense wall are presented in figure 2 below;

Figure 2: Bioengineer Coastal Defense Wall Types

1.2: Erosion Measurement:

Erosion activities leading to various forms of soil loss are quantifiable through erosion measurable techniques. Soil erosion measurement techniques have been in existence for over hundred years with modifications for improvement. Each method has inherent advantages, disadvantages, and regional characteristics; Moreover, researchers should focus on the advantages of each method and gradually improve the current defects to develop these methods in a quantitative, accurate, crossover, and composite directions (LI, 2017). These soil erosion measuring techniques are classified into five distinct groups; Runoff plot technique, erosion pin technique, nuclide tracing technique, model estimation technique, and 3s technique. These can be seen in figure below;

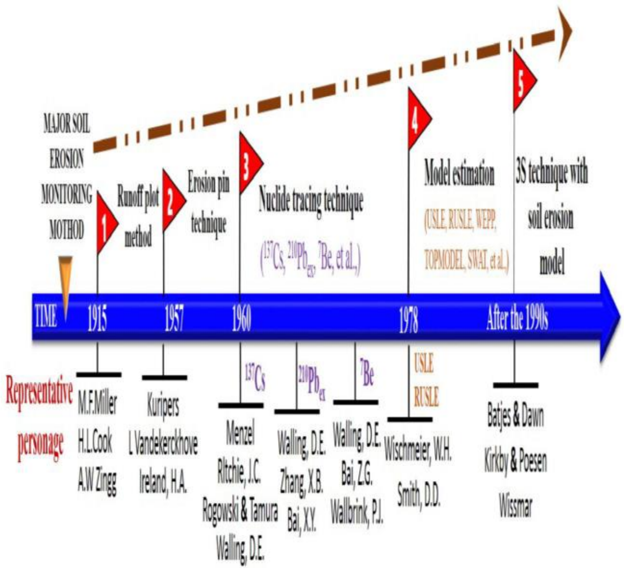

Figure 2: The developing process chat of Method of soil erosion monitoring (LI, 2017).

1.2.1: Runoff Plot Technique:

This technique deploys measuring erosion from the runoff flow. Runoff and sediment collection devices can be as simple as tanks connected to the upstream gutter, installed at plot from edge, by means of a conveyor, in which total washed material (soil and water) yielded in an erosive event is stored and measured.

1.2.2 Erosion Pin Technique:

This method include; driving a pin or pins (Iron, wood, plastic rods, *etc.*, not easily decay able) into selected soil so that the changes in the soil surface level can be measured from the top of the pin which changes in a datum. For example, to estimate gully sides or waterbeds, the pin or rod is driven into the soil. Estimate of the bank retreat is known by the increase in length of exposed pin or rod outside the soil. Pin technique data may be carried out for long duration for diverse research. A curious case of an erosion pin approach is that of the Holme Post which records 130 years (1848 – 1978) of peat wastage in the East Anglian fens, UK (Boardman *et al*., 2016). However, many such studies are for relatively short periods. Thus, the erosion pin technique method can be used for both long and short term erosion measurements. In rapidly changing conditions pins were measured once every 7 to 10 days to the nearest 5mm (Wiggs *et a*l., 1995). Pin types are classified as pin type A, and pin type B according to their placement assigned to various erosion type. Pin type A (Inter – rill) has downhill flow otherwise vertical flow movement. Pin type B (rill) has side (left or right) flow otherwise horizontal flow movement. These pin types can be seen in the figure below;

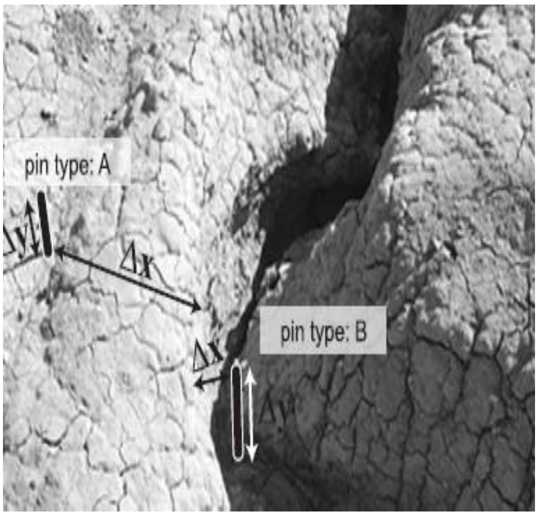

Figure 3: Pin type (Vergari *et al*., 2011).

For any pin type, pin is mounted by inserting into the soil. Pin placement for data collection is shown in figure below;

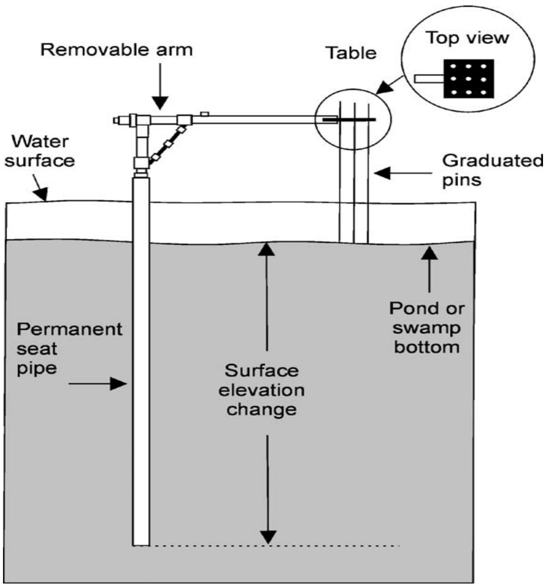

Figure 4: Pin set – up for erosion measurement (Cahoon *et al*., 2002).

1.2.3: Nuclide Tracing Technique:

The radionuclide techniques refer to the use of various elements of different half-life, introduced to the soil through artificial or natural means for soil erosion measurements. They are not suitable for short – term or individual soil erosion events due to sensitivity and background noise problems (Hsieh *et al*., 2009). Of all available tracers, the isotope caesium – 137 ($^{137}C_s$) has become the most developed during the last decade for quantifying soil erosion and deposition, largely as a result of the pioneering research of J.R. McHenry and J.C. Ritchie of the US Department of Agriculture (Loughran, 2016). Another tracer widely used is ^{59}Fe which has half life of 45 days before decaying to stable ^{59}Co. Measurement of radioactive decay in soil samples requires a gamma spectrometer and soil sampling making its high cost unlikely to decrease significantly. Also its high environmental risk potential limits the application of the technique under natural conditions.

These nuclides are introduced to the soil from the atmospheric environment for erosion studies. These processes can be seen in the diagram presented in figure below;

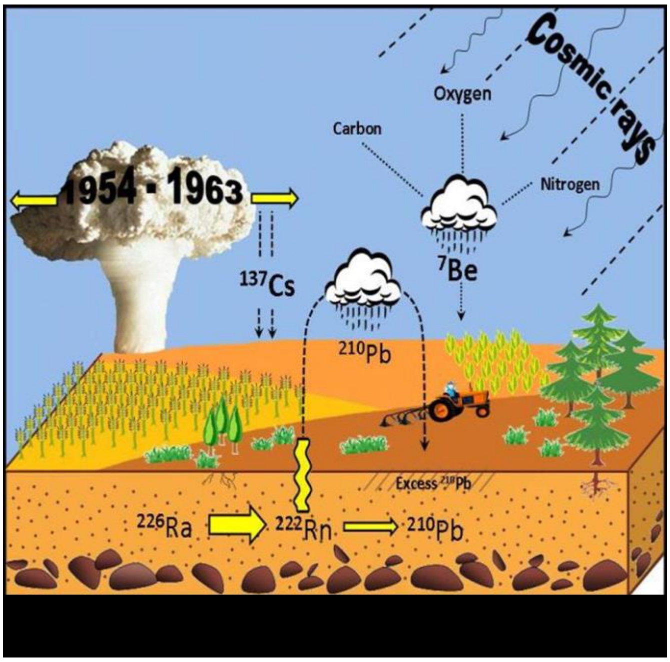

Figure 5: Fallout Radionuclides for erosion studies (Zupanc and Mabit, 2010).

1.2.4: Model Estimation:

Erosion model estimation refers to the use of new or already developed applicable erosion equation in calculating erosion. Erosion models or equation are derived by intensive experimentation, including field and laboratory studies resulting to a numerical or empirical formula that provides the concise description of the processes of detachment, transportation and deposition of soil on lands.

Their exist many erosion models which were developed, namely USLE, and several other empirical models such as Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Loss Equation (MUSLE), which were developed from the concept of USLE itself (Rahim *et al*., 2017). Experimentation carried out at Scone, NSW, showed that this commonly used method of measuring soil loss could lead to serious error, with actual soil loss being underestimated by factor of approximately 3 (Ceiesiolka *et al*., 2004). Thus, they have their limitations as their advantages and disadvantages prevail. Nevertheless, model estimation of erosion provides knowledge of expected result

Models are categorized into three (3) main groups; Conceptual or physically based models, deterministic or stochastic models, and lumped or distributed models.

Conceptual or physically based models are models fabricated on the bases of physical processes which are variables measurable through physical or biological processes. These types of models are applicable in areas different from where the original model fabrication data were obtained. A typical example of this conceptual or physically based model is the large body of data collected in USA and summarized in the universal soil loss equation (USLE) database by wischmeier and smith in 1978.

Deterministic and stochastic models are models designed to produce the same output for the same set of input variables (deterministic) or to produce result that describes possibilities of a given prediction with at least one probabilistic input. Examples of stochastic models include the climate generator for the WEPP model or the return period analyses associated with peak runoff events from the Curve Number technology (USDA, 2010).

Lumped and distributed models are models designed on the assumption of inputting variables (soil, climate condition, erosion, vegetation, *etc*.) in a single set (lump) or many individual sets (distributed) to describe the entire processes. The Rational Peak runoff method and the Curve Number runoff and peak flow models are common examples of lumped models (Ward *et al.,* 1995). Incorporation of road network and their impacts on watershed analysis is an example of distributed modeling. This technology has the potential to include the impacts of roads as sources of sediment and runoff and also to evaluate the effects of roads on fish passage (RMRS, 2007). Lumped and distributed models are shown in figure below, where lumped describes the entire structure as a single structure while distributed model describes the entire structure as many individual grid cells, each possessing their individual structural recognition. These two structures can be seen in the figure below;

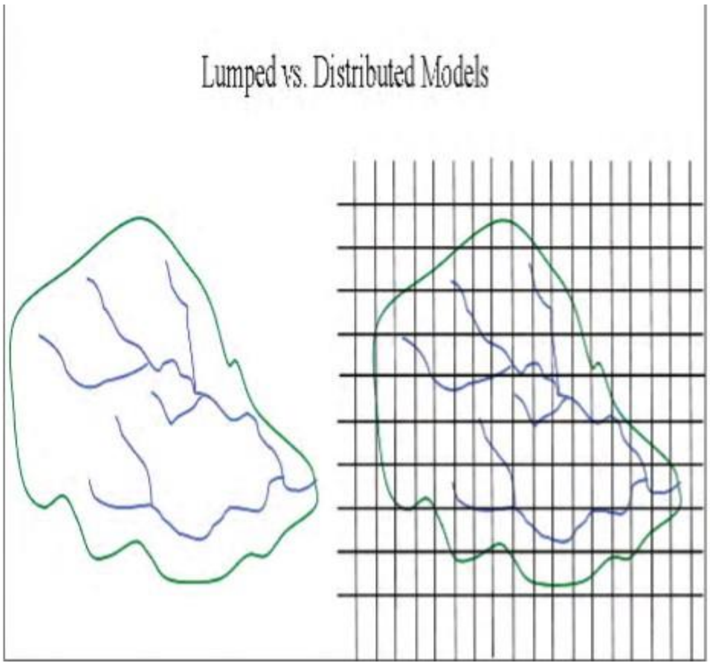

Figure 6: Lumped and Distributed Model structure (USDA, 2010).

1.2.5: 3s Technique with Erosion Models:

This refers to soil erosion measurement techniques developed after 1960 prior combination of the 3s method and erosion models. Examples include the simple proportional model developed by Walling *et al.* (2011) for ^{137}Cs was used to convert Pu increases in inventories (positive inventory reductions) into sedimentation rates and the inventory method (IM) published by Lal *et al.* (2013) was used to convert $^{239+240}$Pu inventory reductions into soil erosion rates.

2. Materials

The materials used in actualization of this work include;

The study area: Delta state of Nigeria is presented in the map in figure 8 below;

III. Map of Nigeria Showing Location Of Delta State **IV. Map Of Africa Showing Location Of Nigeria**

Figure 7: Map of the Study Area

Other materials include; 8.0 mp camera, Thermometer, Concrete water defense wall, Anemometer, Measuring tape, PVC pipes, *etc*.

3. Methods

The Pin technique with relevant models was used in the actualization of the presence of erosion. According to Karambas, (2014), the shear stresses (τ_{sx} and τ_{sy}) at the water surface in the x and y directions respectively represent the vertical boundary condition as follows:

$$\tau_{sx} = \rho k W_x \sqrt{W_x^2\ W_y^2} \quad \text{(Eq. 1)}$$

$$\tau_{sy} = \rho k W_y \sqrt{W_x^2 + W_y^2} \quad \text{(Eq. 2)}$$

Where:

k is the surface friction coefficient [kg/ m^3] typically of the order of 10^{-6} (here we assume

k = 0.000001 / 0.000003); W_x and W_y are the wind speeds in x and y directions [m/s], respectively, ρ is water density obtained using okolotu and oluka (2021) method. The necessary computations are tabulated below;

Table 1: Water density computation

S/N	**Temperature, T (ºC).**	**Salinity (in mg/L)**	**Density of water, ρ in (kg/m3)**
1	31.3	0.00	995.279
2	33.0	0.00	994.734
3	31.3	0.00	995.279
4	31.0	0.00	995.372

The shear stress (τ_{sx}) at the water surface in the x and y directions are computed in table below;

Table 2: Shear stress at the water surface in the x and y direction

S/N	Density of water, ρ	Surface Friction Coefficient, k (kg/ m^3)	Wind speed in x direction, W_x (m/s)	Wind speed in y direction, W_y (m/s)	W_x^2 (m/s)	W_y^2 (m/s)	$\sqrt{W_x^2+W_y^2}$	Shear stress in x direction	Shear Stress in y Direction
1	995.279	0.3333	0.4927	0.8429	0.5048	0.7105	1.5534	253.8902	434.3497
2	994.734	0.3333	0.4360	0.6632	0.1901	0.4398	1.0992	158.8933	241.6927
3	995.279	0.3333	0.4915	0.4891	0.2416	0.2392	0.9806	159.8805	159.0998
4	995.372	0.3333	0.7208	0.7853	0.5196	0.6167	1.5061	360.1549	392.3830
Av.	995.166	0.3333	0.5353	0.6951	0.3640	0.5016	1.2848	233.2047	306.8813

4. Results

Results of shear stress in x and y direction is presented in below;

Table 4: Result of shear stress in x and y direction

S/N	Shear stress in x direction	Shear Stress in y Direction
1	253.8902	434.3497
2	158.8933	241.6927
3	159.8805	159.0998
4	360.1549	392.3830
Average	233.2047	306.8813

The shear stress in x and y direction are presented in figure 9 and 10 below;

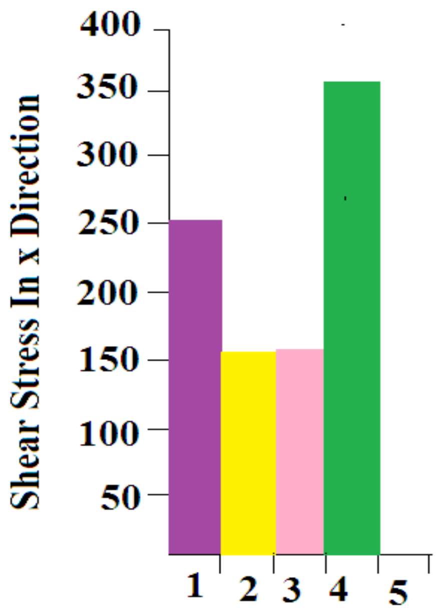

Figure 8: Shear stress in x direction

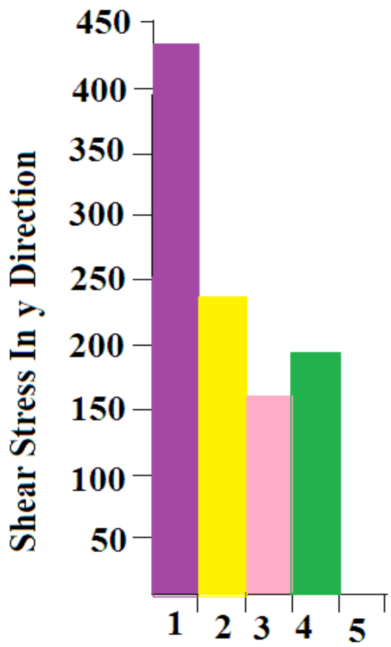

Figure 9: Shear stress in y direction

5. Discussions

The shear stress results for x and y direction are 233.2047 and 306.8813 respectively. These are the average force pulling towards the wall. In the absent of defense wall, these amounts of force tend to destroy valuable structures or even facilitate erosion.

The water defense structure used for this research assessment is classified as hard armoring of bioengineering technique. Several holes were bored with PVC pipes sized shapes on the defense wall to aid gradual water draining. This also aids reduction of pressure exerted on the defense structure. This can be seen in the figure below;

Figure 9: Water Defense Wall View

The defense structure also benefits seasonal variations in rainfall of the study area which has a dry season during the beginning and end of the year and a wet season during the mid-quarter of the year. Recession and advancement of the water body away and towards the defense structure.

6. Conclusions

From results obtained, shear stress impact was notably observed to be significant in wearing off the coastal structures. This work serves as a useful tool for the design and redesign of new and existing coastal structures by water engineers in Coastal Engineering works.

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