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TRACING THE TRAVELLING OF STRESS DEFORMATION WAVES IN COASTAL REGION OF NIGERIA USING GLOBAL POSITIONING SYSTEM (GPS)

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ABSTRACT

The availability of precise and reliable deformation information is critical for the monitoring and analysis of the earth's surface displacement, the movement of fault, landslides and some other deformations. In addition, proper site selection of important structures and their protection against hazards and the ability to analyse and predict natural and non-natural hazards are of great importance in geosciences. Monitoring of deformation in Coastal region of Nigeria is of great importance, providing useful information to assess seismic hazard and risk. Natural hazards that have disastrous impacts on humans include earthquakes, landslides, floods, storm surges, severe winds, bushfires, and tsunamis. Thus, this study involves the use of the Nigerian Continuously Operating Reference Station (CORS) in Coastal region for tracing and analyzing stress deformation wave along the coastal region of Nigeria. NIGNET GPS data for the periods 2012 and 2013 were collected and processed on same phases. From the comparative analysis between the 1st, 3rd campaigns and 2nd, 4th campaigns show that there was a small significant displacement in the vertical direction, of approximately 0.39mm/yr and 0.47mm/yr. Both the magnitude and direction of the whole changes agree well with the velocity of approximately 0.4mm/yr and 0.5mm/yr. The relative horizontal positions of the changes are not notably affected from the local geological features. This implies that the faults and/or landslide bodies near those stations used are relatively stable.

KEYWORDS: Deformation Monitoring, GPS; NIGNET, Tracing Stress, Velocity

INTRODUCTION

Deformation has caused hundreds of thousands of casualties in the world during the past decades. The hazard will increase in the future as many threatened areas are in developing countries where population is fast growing. Nothing will prevent future deformation from happening, so preparedness is the best way to mitigate the hazard. Understanding the nature of deformation is essential to identify where and when potential danger arises. Certain deformation monitoring environments pose severe limitations on the achievable precision that can be attained by instrumentation used to monitor deformation behaviour. Large open pit mines, subsidence, landslide, earthquakes and volcanic eruption are such examples. The steep walls of these events limit the effectiveness of Satellite Positioning technologies by masking some satellite signals and thereby diluting the geometric strength of solutions.

The coastal lines of Nigeria is about 1000km long on the Gulf of Guinea, bordering nine states of Lagos, Ogun, Ondo, Edo, Delta, Bayelsa, Rivers, Akwa Ibom and Cross Rivers, Figure 1 below. While the first five states are west of the River Niger, the last three states are east of the Niger with the last, Bayelsa state, straddling the river. Geologically, coastal Nigeria is covered by two sedimentary basins; the Keta basin and Niger Delta basin. The Keta basin (also called the Benin or Dahomey basin in Nigeria literature) is a transboundary basin that extends from Ghana through Togo and Benin to Nigeria. The Niger Delta basin is separated by the Okitipupa Ridge [10].

The Keta basin constitutes parts of a system of West African margin developed during a brief period of rifting in the late Jurassic to early Creteaceous, associated with Benin Trough complex. It was accompanied by an extended period of thermally induced basin subsidence through the middle to upper Cretaceous to tertiary times as the South American and African plate entered a drift phase. The onshore portion of the basin covers a broad arc shape profile approximately 600km^2, attained a maximum width of 65km at the basin axis along the Nigerian border with the Republic of Benin. It narrows to about 25km west and eastwards. It is along its northeastern fringe (the okitipupa structure), that a band of tar sand (oil sand) and bitumen seepage occurs [10].

The basin covers the southern areas of Lagos, Ogun and Ondo states in Nigeria and stretches into the neighbouring countries of Benin, Togo, Ghana and Ivory Coast. In the Keta basin, urbanization and over-abstraction is substantially increasing [1].

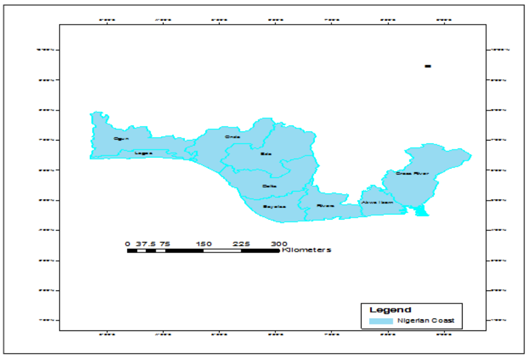

Figure 1: Map of Coastal Areas of Nigeria

The Niger Delta is a coastal arcuate delta of the River Niger covering an area of about 75,000km^2. The sub aerial Niger Delta has an extensive saline/brackish mangrove swamp belt separated from the sea by sand beach ridges for most of the coastline. Geologically, rocks of the Niger Delta are subdivided into three formations, which are Akata, Agbada, and Benin formations [14]. The Benin formation consisting predominantly of massive highly porous sands and gravel with locally thin shale/clay interbeds [5]. The Agbada formation consists of the sand reservoirs where oil and gas are produced, while the Akata formation consists of a uniform shale rocks.

The current development in the Niger Delta with respect to oil exploration leaves much to be desired. Fluids are being extracted without replacement. As a result of this activity, most cities in the oil producing states are exposed to various degrees of environmental hazards such as subsidence, landslides and earthquakes. The determination of the rate of travels of the stress-deformation wave becomes imperative. This research attempts to investigate the rate at which this stress-deformation wave travels in these areas.

JUSTIFICATION

Today much consideration is given in preventive risk management for crucial and sensitive infrastructures where a failure cannot only impact the population and cause significant human life lost, but can run economy of a region, a country or a nation.

In case of disaster, the media often show impressive pictures related to the visible dramatic situation, but rarely comment on how the global economy is affected [8]. For instance when a deformation (landslide or an earthquake) happens, the report shows images of dissolution and destruction of building and properties while the vital infrastructures impacted will not only affect the rescue and emergency services but also the economy on the long run. The need to forestall or prevent environmental hazard in areas prone to earthquake or subsidence activities has become imperative. Similarly, time series analysis and velocity modelling for estimating rate of deformation as well as baseline data in the coastal area of Nigeria for disaster preparedness are useful tools towards disaster prevention.

MATERIALS AND METHODS

In this study, the stress deformation of the coastal lines of Nigeria where investigated using the Nigerian Continuous Operating GNSS Reference station data. The coastal line is about 1000km long on the Gulf of Guinea as the longest coastal lines of Nigeria. The stress deformation measurement of coastal lines of Nigeria involved four (4) measurement campaigns. Table 1 shows the measurement campaigns carried out.

Table 1: Measurement Campaigns

Year	Day of the Year (Doy)	Month of Campaign
2012	1 - 5	January (1st)
2012	137 - 141	May (2nd)
2013	1 – 5	January (3rd)
2013	137 – 141	May (4th)

The first campaign was carried out in January, Day-of-the-year (DoY) 1-5, 2012, the second campaign in May, DoY, 137-141, 2012, the third campaign in January, DoY 1-5, 2013 while the last campaign in May, DoY 137-141, 2013. This was done in order to have the same phase.

Data from four (4) NIGNET stations forming the monitoring stations were collected based on the campaigns as indicated in Table 1. The stations are as shown in Table 2, Figure 2, shows the location of the monitoring stations within the context map of Nigeria.

Table 2: Monitoring Stations Information

Station ID	Station Locations	Receiver	Antenna(m)	Antenna Height (m)	Approximate Latitude (N)	Approximate Longitude (E)	Ellipsoidal Height(m)
UNEC	University of Nigeria, Enugu Campus	Trimble	Choke Ring	0.1710	$06^0$25’29.301”	$07^0$30’17.968”	254.4055
ULAG	University of Lagos, Lagos	Trimble	Choke Ring	0.1710	$06^0$31’2.375”	$03^0$23’51.444”	44.5752
RUST	River State University. of Science and Technology Port Harcourt	Trimble	Choke Ring	0.1710	$04^0$48’6.609”	$06^0$58’42.677”	45.5892
CLBR	University of Calabar	Trimble	Choke Ring	0.1710	04^0 57’ 1.081’	08^0 21’ 5.643’	57.2299

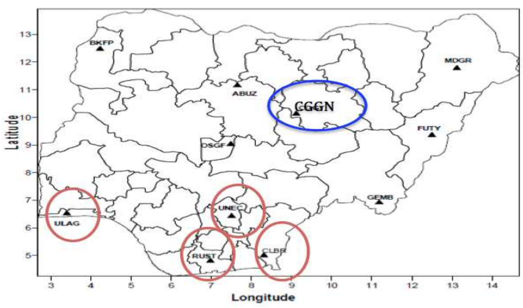

Figure 2: Location of Reference Station (Circled in Blue) and Monitoring Stations (Circled in Red); (Source [5])

To obtain the absolute displacement from stress deformation analysis, it is desirable to utilize a stable and precise IGS [7] reference stations close to the monitoring stations. To this end, the IGS Station at Centre for Geodesy and Geodynamics, Toro, with station ID CGGN was used as the reference station as shown in Table 4 and Figure 2.

Table 3: Reference Station Information

Station ID	Station Locations	Receiver	Antenna (m)	Antenna Height (M)	Approximate Latitude (N)	Approximate Longitude (E)	Ellipsoidal Height (m)
CGGT	Centre for Geodesy & Geodynamics, Toro	Trimble	Choke Ring	0.1710	$10^0 07'23.141''$	$09^0 07'5.922''$	916.4462

Data Processing Strategy

Twenty-Four hours (24hrs) of GPS RINEX data of the monitoring stations (RUST, ULAG, CLBR, and UNEC) were downloaded from the NIGNET website at www.nignet.net covering the periods of the GPS campaign. Similarly, corresponding data periods of the reference station (CGGN) were obtained from the IGS website.

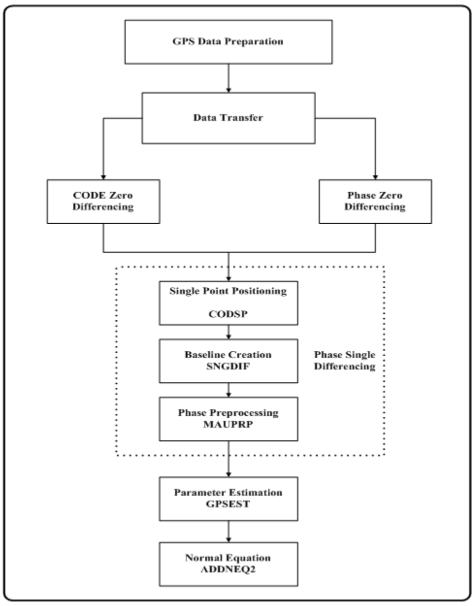

Figure 3: Data Processing Procedure Employed in the Bernese GPS Scientific Software Version 5.0 [3]

Table 4: Baseline Length between the Reference and Monitoring Stations

Baseline	Baseline Length (km)
GGN-RUST	636.2
CGGN-ULAG	749.1
CGGN-UNEC	446.7

Since the baselines are hundreds of kilometers in length (Table 4.0), therefore it requires sophisticated data processing software to achieve high accuracy results. The Bernese GNSS Scientific Processing software version 5.0 was employed for GPS data processing. The software is suitable for scientific studies in surveying fields that require high precision such as zero order GPS network. By implementing the Bernese software, data cleaning, cycle slip detection, ambiguity resolution and network adjustment of GPS data were achieved to meet the desired criteria. Subsequently, approximate coordinate, estimated coordinate, à posteriori variance factor and variance-covariance matrix were yielded from the GPS data processing. These parameters are required in order to perform the two-epoch deformation analysis. In other words, these parameters are the inputs of deformation analysis. Figure 3 shows the main workflow of GPS data processing using Bernese. The processing options used are shown in Table 5.

Table 5: Processing Options

RINEX data at 1 second sampling rate,
IGS final orbit,
24 hours sliding window processing,
Ocean tide loading,
ITRF 2008 reference frame,
Cut-off satellite elevation angle at 10^0,
Quasi-Ionosphere free (L3) ambiguity free,
Troposphere delay mapping function of f (z) = 1/cosz, using Saastamonien model,
Control station coordinate constrained.

RESULTS AND DISCUSSIONS

To obtain precise relative displacement, it is desirable that one relative stable station of IGS is used as the datum of deformation analysis and the GPS network for displacement analysis is adjusted using a constrained free network adjustment method. In this research, the CGGN station is considered as a relatively stable point. The analysis focuses on the pattern of the velocity vectors, the mode of the deformation either in the vertical direction or in the horizontal direction and finally to deduce where stress are likely to concentrate along the coastal region.

Deformation Analysis

To achieve a reliable deformation analysis results, the solution of the deformation analysis of coastal region needs to be stable and precise enough. The precision and stability of the network solutions are strongly related to the amount of GPS measurements used to generate the solution, which is usually measured in the length of observation time (for a given sampling rate). Research on the amount of data required has been conducted and solution from a minimal of 24 hours data was considered stable and precise enough for a high precision deformation monitoring and analysis [2]. However, there is a number of important factors that contributed to the stability of this GPS network solution, such as length of the observation time, the amount of valid data collected, baseline length, quality of GPS signal recorded, the station environment (e.g. multipath, solar activities, satellite status), and cycle slip, etc. Many of these factors vary with time. Therefore, it is necessary to investigate properly the amount of data required to generate a reliable and precise solution from the deformation analysis of the coastal region of Nigeria.

Comparison of the January 2012 (1st) and January 2013 (3rd) Campaigns

In Figures 4 and 5 representing the January 2012 and January 2013 campaigns respectively, the results from the estimated velocity shows that, the rate of deformation in CLBR and UNEC are insignificant as observed on both vertical direction (VU) and horizontal direction (VN and VE). For ULAG point, a significant deformation along the vertical direction was observed. Although the observed change is not much, it shows that there is occurrence of deformation in the vertical direction in Lagos at the rate of approximately 0.39 mm/yr. At RUST station, it was not possible to investigate the deformation rate due to non-availability of data.

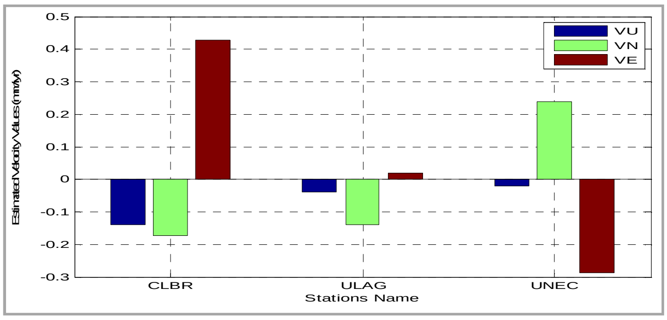

Figure 4: The Precision Solution of Deformation and Reference Site of the Study Area in the 1st Campaign

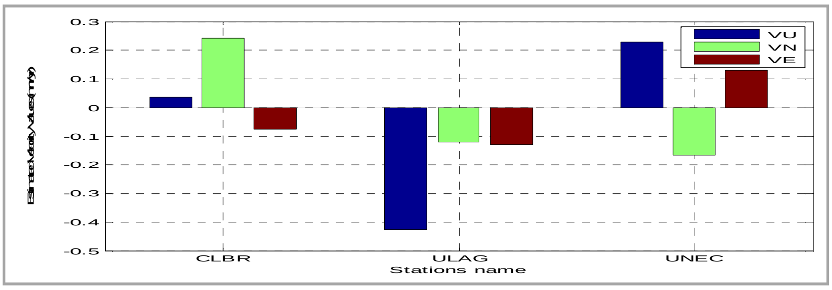

Figure 5: The Precision Solution of Deformation and Reference Site of the Study Area in the 3rd Campaign

Comparison of the May 2012 (2nd) and May 2013 (4th) Campaigns

During the 2nd and 4th campaigns, there was no data for monitoring points CLBR and RUST. Figures 6 and 7 representing campaigns carried out in May 2012 and May 2013 reveals ULAG monitoring station showing significant changes in the vertical direction (VU) at the rate of about 0.47mm/yr. This further confirms that there is minimal deformation occurrence along the coastal region of Lagos. At UNEC, the changes are insignificant. Since the precision of horizontal coordinate (VN and VE) is less than that of the vertical displacement, the relative displacement of this station points are not precise and reliable enough for high precised deformation analysis. Therefore, the relative horizontal displacement was not analyzed.

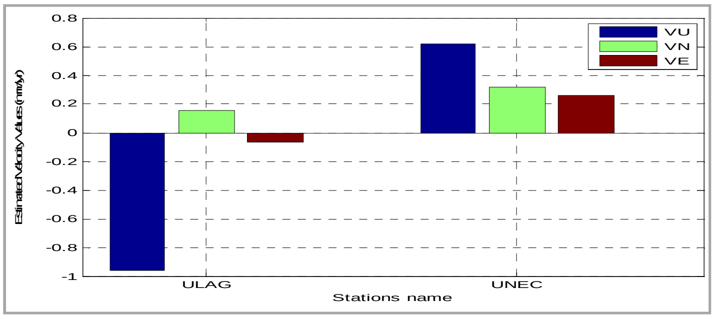

Figure 6: The Precision Solution of Deformation and Reference Site of the Study Area in the 2nd Campaign

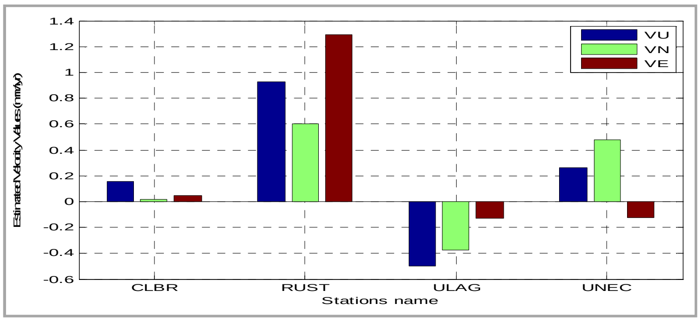

Figure 7: The Precision Solution of Deformation and Reference Site of the Study Area in the 4th Campaign

Tracing the Stress

It is not possible to have deformation without having stress. From the result, it was observed that there is a force of contraction (stress) around Lagos compared to other coastal areas in Nigeria that are more stable. The southern Mid-Atlantic Ocean is characterised by four major seismologically active fracture zones or trenches [9]. According to Neev and Hall, (1982) the most prominent ones are the equatorial fractures – Saint Paul, Romanche and Chain Fractures and the other one – Charcot Fracture Zone can be found in the Northern part of South Atlantic Ocean. These fracture zones extend into the landmass of West African countries expecially Ghana and Nigeria and the epicenters of the West African intraplate earthquakes had been located along their inland extensions. The causes of these intraplate earthquakes had been probably attributed to stresses propagated from the tectonic activities across the Mid-Atlantic Fracture Zones [12]. There is always a tendency of the earth system to maintain a state of equilibrium and this results into intraplate deformation along fault planes due to tectonic isostatic adjustment. Lagos state and some parts of Ogun state are in the western part of the fault that runs through Ijebu-Ode, Ifewara and to the Northern Nigeria from the Atlantic Ocean [11]. Therefore among all other factors, the deformation observed in Lagos State could be as a result of tectonic isostatic adjustment from the seismic activities along African and South American plate boundary and adjoinig faults or fracture zones.

Another possible reason while stress might be more in Lagos than other coastal regions of Nigeria could be as a result of soil liquefaction because of the loose sediment nature of Lagos. This liquefaction arises when saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition like cyclic or shock loading [6]. Due to loose sediment nature of Lagos, the soil has the tendency to decrease in volume when subjected to shearing stress, when this saturated soil are sheared, the soil grain tend to rearrange into a more dense packing with less space in the voids, as water in the pore spaces is forced out. As the drainage of the pore water impeded, Pore water pressure increases progressively with the shear load (stress moving along the boundary). This will lead to transfer of stress from the skeleton to the Pore water precipitating a decrease ineffective stress and shear resistance of the soil. When the shear resistance of the loose sediment becomes less than static, driving shear stress, the soil is said to undergo deformation. As a result of the loose nature of the sediment water found its way out thereby creating a vacuum beneath the subsurface which may lead to stress.

CONCLUSIONS

From the comparative analysis between the 1st, 3rd campaigns and 2nd, 4th campaigns shows that there was a small significant displacement in the vertical direction, of approximately 0.39mm/yr and 0.47mm/yr. Both the magnitude and direction of the whole changes agree well with the velocity of approximately 0.4mm/yr and 0.5mm/yr. The relative horizontal positions of the changes are not notably affected from the local geological features. This implies that the faults and/or landslide bodies near those stations used are relatively stable. This research indicates that the methodology of data processing and deformation analysis is feasible and effective. However, further investigation is required when more NIGNET data is used to cover a larger chronological span and more NIGNET stations are used for deformation analysis.

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