`

DEFORMATION MONITORING OF TANGA TIDE GAUGE CONCRETE STRUCTURE

A Case Study of Tanga tide gauge

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geomatics (BSc. GM) of Ardhi University

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University, a dissertation titled "**Deformation Monitoring of Tanga Tide Gauge Concrete Structure**", in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics of the Ardhi University, Dar es salaam

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Ms. Valerie Ayoub

Date………………………………

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I, Nguno Deus G, hereby declare that this dissertation is my own original work and that to the best of my knowledge, it has not been presented to any other University for a degree or any other similar award.

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Nguno Deus G

(22770/T.2023)

Candidate

Date: ……………………………….

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DEDICATION

I dedicate this dissertation to my beloved parents Mr. and Mrs. Raphael Nguno, my brother Denis Nguno, my sisters Diana Nguno and Digna Nguno for their valuable prayers, support, love, patience, encouragement and care throughout my study.

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ABSTRACT

This study reports the monitoring of structural deformations of Tanga tide gauge concrete structure found in Tanga City at the Tanga port. Since its construction in 2016, two epochs of both horizontal and vertical deformation have been observed. The first epoch in 2018 and the second in 2021. This study analyses the deformation of the Tanga tide gauge concrete structure after second epoch of observation. Both vertical and horizontal observations were carried out. For vertical measurements, a loop of 224.5m back and forth was carried out to obtain the orthometric height of object points. The misclosure obtained was approximately 1 mm. Tachometry observation was carried out to obtain the horizontal position of the object points. A total station was set on MP1 which is a monitoring point and orientated to NAVI for datum check and then the object points were observed to obtain their two dimensional coordinates in WGS84 coordinate system. The datum check was within acceptable limits which is 1:14310.

The magnitudes of the vertical displacement of the object points were calculated based on the height differences between the observations of the second and the third epoch. The calculated vertical displacement magnitudes were compared with their corresponding calculated 95% confidence intervals to determine the significance of reported movements/displacements. The Calculated displacements (i.e. 3.6 mm, 4.1 mm, 5.8 mm, 7 mm, 2 mm, 1.8 mm and 7.2 mm for points DP1, DP2, DP3, DP4, DP5, DP6 and DP7 respectively) between the second and third epoch shows that the structure changes shape vertically at the 95% confidence level. On the other hand, the horizontal displacements are relatively insignificant and at 95% confidence level they are not significant enough to have caused horizontal deformation.

Keywords; Tide Gauge, Global Positioning System, Total Station, Level, Deformation

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ACRONYMS AND ABBREVIATIONS.

TGBM	- Tide Gauge Benchmark
GPS	- Global Positioning System
TS	- Total Station
TPA	- Tanzania Port Authority
GNSS	- Global Positioning System
TTG	- Tanga Tide Gauge
RADAR	- Radio Detection and Ranging
NOAA	- National Oceanic and Atmospheric Administration
TMA	- Tanzania Meteorological Agency
WGS84	- World Geodetic System 1984
CCIAM	- Climate Change, Impact Adaptation and Mitigation
CGPS	- Continuous Global Positioning System
DGPS	- Differential Global Positioning System
PPM	- Parts Per Million
MSL	- Mean Sea Level
ITRS	- International Terrestrial Reference System
ITRF	- International Terrestrial Reference Frame
VLBI	- Very Long Baseline Interferometry
SLR	- Satellite Laser Ranging
InSAR	- Interferometric Synthetic Aperture Radar

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CHAPTER ONE

INTRODUCTION.

1.1 Background of the study.

Deformation refers to changes in dimension, shape, size and orientation or position that a structure may undergo as a result of both external as well as internal factors. It can be influenced by numerous factors that are both man made like excavations, construction, mining activities etc. as well as natural factors like weathering, soil erosion, subsidence etc. (Adam, 1990).

Deformation monitoring generally refers to systematic measurement and tracking of the alteration/change in shape, or dimensions of a structure as a result of stress induced by applied loads. It is well known that you can't keep track of what you don't measure, therefore, in order to track the deformation pattern/ monitor the deformation, a series of measurements has to be observed at a specific time interval (Sofia, 2018). Deformation monitoring is a key aspect of assessing the structural health and stability of any infrastructure. By analyzing the movement and deformation of a structure over a specific period, it is possible to identify potential risks, ensure ongoing stability, and implement necessary maintenance measures. Therefore, this research focuses on the deformation monitoring of the Tanga tide gauge concrete structure to evaluate its structural integrity and stability (David, 2006).

A tide gauge is used to determine the variations in sea level in relation to a reference height (datum). The rise and fall of tides have a significant impact on the natural environment and can have a significant impact on activities related to the sea such as hydrographic surveying. It is a part of a modern water level monitoring station equipped with sensors that constantly track the height of the water level in the surrounding area. This information is crucial for a variety of coastal activities, including safe navigation, sound engineering, and the preservation of habitats. In addition to more accurately measuring tidal heights, modern water level monitoring stations can also measure other oceanographic and meteorological factors, such as wind speed and direction, air and water temperature, and barometric pressure. The National Oceanic and Atmospheric Administration (NOAA) utilizes this data for various purposes, including ensuring safe navigation, keeping track of and predicting sea level trends and other ocean conditions through forecasts and now casts, and publishing annual tide predictions (NOAA, 2023). The goal of deformation monitoring is to find out whether or not movement is occurring and whether or

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not the structure is safe and stable. Tanga tide gauge deformation is caused by its load, water loading effect (which reaches nearly 2m), and erosion. The gauge is built in water near the shoreline, and water has eroded some of the material beneath the structure's foundation, leaving it vulnerable to deformation factors. Figure 1.1 below shows the location of the tide gauge in Tanga harbor

Figure 1.1 Location of the tide gauge at Tanga harbor

Deformation monitoring of the tide gauges has been done in different parts of the world with different methods as analyzed below;

The stability of tide gauges in the south pacific determined from multi epoch geodetic levelling. Tides gauge data is critical for determining changes in sea levels, both globally and locally, in relation to a global reference frame. Data from precise measurements between tide gauges and coastal and inland markers, including CGPS benchmarks, are used to assess the stability of tide gauges located in 12 locations throughout the South Pacific. The analysis is based on a constant 2 velocity model that minimizes any changes in the benchmarks surveyed since the tide gauges

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were installed. Except for the Solomon Islands, no motion was detected at a 95% confidence interval relative to the CGPS benchmarks. The results for the Solomon Islands, however, are deemed untrustworthy due to the recent establishment of the CGPS benchmark and limited surveying. The tide gauges in Tonga and Cook Islands were impacted by survey errors, while the results for Vanuatu were affected by earthquakes (Craig, 2023).

Geodetic deformation monitoring around Trabzon tide gauge station. This study used GNSS measurements to investigate three-dimensional deformations around the TRBZ tide gauge station in the Eastern Black Sea region, Trabzon province, sea port area. A geodetic GNSS control network was established in the study area for this purpose. Three reference points and two object points comprise the GNSS network. Two periods of static GNSS measurements were carried out in the GNSS network, in June 2020 (1st Period) and October 2020 (2nd Period). The GNSS measurements were evaluated using Magnet Work Tools v5.1 software. The coordinate differences (base components) Delta X, Delta Y, and Delta Z of the points in the WGS-84 system, as well as the variance-covariance matrices of these differences, were obtained after evaluating the measurements. Following this, the adjusted coordinates of the points and variance-covariance matrices were obtained by adjusting each period using the algorithms written in the MATLAB R2016b program using the free network method. Theta (2)-criterion was used to examine deformations that occurred between different periods using the static deformation model. All calculations in this study were performed using MATLAB program codes that they wrote (Demirsoy &Yilmaz, 2021)

Strategies for long term monitoring of tide gauge using GPS the records of changes in the Mean Sea Level (MSL) in relation to Tide Gauge Benchmarks (TGBM) are affected by vertical land movements. In order to get accurate measurements of changes in the absolute sea level, these MSL records must be corrected for the changes in ground level at the tide gauge sites. For over a decade, the Global Positioning System (GPS) has been utilized to determine the positions of TGBM’s and monitor any changes in their positions over time within the International Terrestrial Reference System (ITRS). This was done through either occasional GPS campaigns or continuous GPS (CGPS), or a combination of both. Recent advancements in the ITRS, satellite orbits, and systematic effects mitigation models allow for the determination of station positions using GPS with a high level of accuracy, at the centimeter or even millimeter level. However, it

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is still debated that long-term estimates of changes in the vertical component cannot be achieved at the 1mm/year level, making comparisons between GPS and other methods necessary (Felix, 1996). Ardhi University built and installed the Tanga tide gauge in 2016 as part of the Climate Change, Impact Adaptation, And Mitigation (CCIAM) program. The installation and data are used for scientific climate change research, practical training, and daily users such as the Tanzania Meteorological Agency (TMA) and Tanzania Port Authority. The Tanga tide gauge station uses two types of tide gauges: one is a hydrostatic pressure gauge located on the lower part of the structure and the other is a radar gauge located on the upper part. All of the gauges are anchored to a fixed reference point on the structure. However, due to soil erosion and instability in the ground, the area near the structure may have shifted, affecting the initial set up of the station. Therefore, it's important to keep an eye on the structure as the network for measuring deformation has already been established. Previous study by Shida (2021) involved a network construction of DP4, DP5, DP6, DP7 and MP03 points and performed GPS observation, levelling and tachometry and concluded the structure is only deforming vertically at 0.9mm/year while the study by Leonard 2018 involved less observations and concluded the structure is deforming only vertically and not horizontal. This study aims to conduct third epoch measurements to monitor the deformation of the Tanga tide gauge concrete structure

1.2. Location of the study area.

The tide gauge station at Tanga is located at Tanga Port harbor with coordinates (Latitude 05° 04´ S, Longitude 039° 06´ E) and it is shown on the figure1.2

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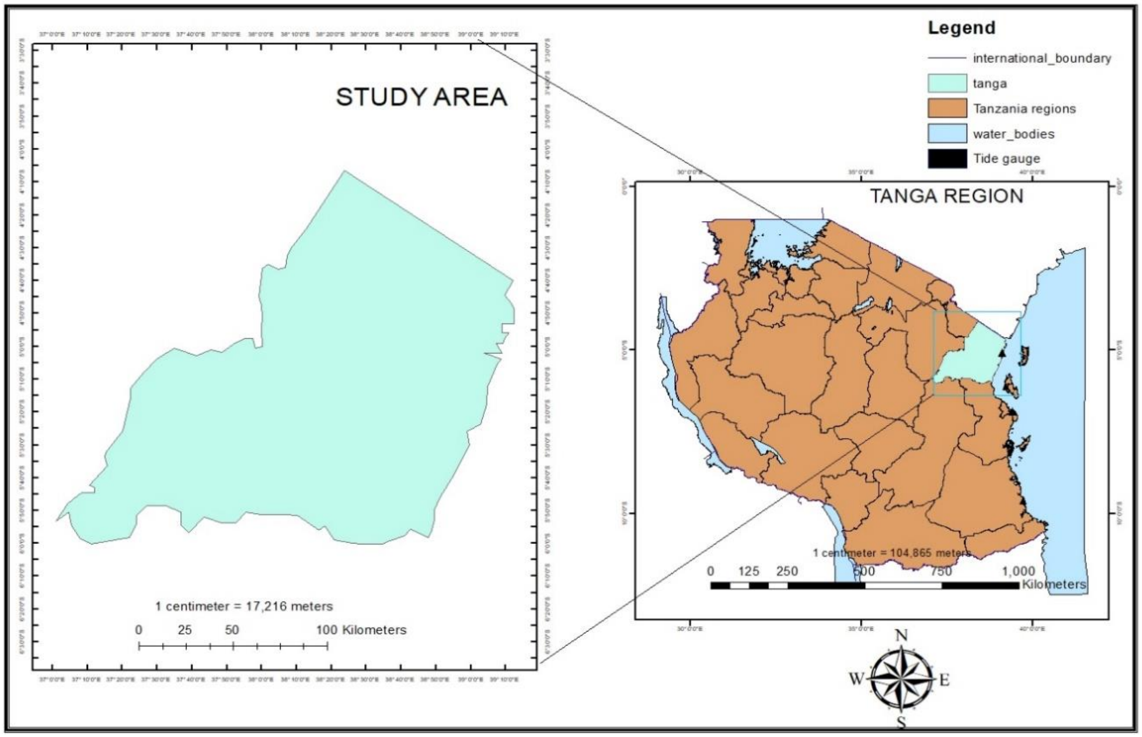

Figure 1.2 Tanzania tide gauge network

1.3 Problem statement

The Tanga tide gauge is constructed on a concrete heavy structure in water near the shoreline and water has eroded some material under the structure foundation leaving it exposed to deformation factors. Monitoring deformation on Tanga tide gauge is due to its load and water loading effect which reaches almost 2m and erosion which has been taking place for a long time now. Erosion may be weakening the structure and distort its initial setup and cause deformation. As a result, incorrect tidal readings from both the pressure and radar sensor may be misleading. Therefore, this study aims to conduct third epoch measurements to monitor the deformation of the Tanga tide gauge concrete stricture.

1.4 Research objectives

1.4.1 Main objective

The main objective of this research is to conduct third epoch measurements to monitor the deformation of the Tanga tide gauge concrete structure

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1.4.2 Specific objectives

The following are the specific objectives

i. To carry out levelling observations to obtain orthometric height of object points
ii. To carry out angle and distance observations in order to compute the horizontal coordinates of object points on the structure
iii. To analyze the horizontal and vertical displacement for the purpose of determining if a measured displacement is significant enough to warrant a response
iv. To determine the horizontal displacement of the Tanga tide gauge concrete structure
v. To determine vertical displacement of the Tanga tide gauge concrete structure

1.5 Scope and limitation

The research is limited to 2D deformation monitoring network in which one benchmark based on the mean sea level is used for vertical positioning and three established controls are used for horizontal positioning.

1.6 Significance of the research

The tide gauge data is used as an indicator of evaluation and impact of global climate change to capture a variety of local and regional phenomena related to decadal climate variability, tides, storm, tsunami and other coastal processes. Tide gauge data are used to validate ocean models and detect errors and drift in satellite altimetry. The tide gauge is useful in sea level hazard warning systems; tsunami detection is requiring near real-time sea-level measurements close to their source area. The tide gauge is a preferred source of information. For sea level hazard warning system both sea level measurements with tide gauge and GNSS technology is used. Since the tide gauge has a variety of important applications, it is then very important to monitor its deformation pattern to obtain correct measurements which is the primary aim of this research. Improved understanding of the concrete structure of the tide gauge and identify patterns that may have taken place since the last epoch. The research may suggest possible measures that must be undertaken to control the deformation of the concrete structure

The beneficiaries of this research are hydrographic surveyors when conducting bathymetric surveys, oceanographers for navigation, Ardhi University who are the primary stake holders of the Tanga tide gauge station and this research is the effort to make sure the station is working

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properly and all other users of the tide gauge data since the tide gauge data is muchly depending on stability of the structure.

1.7 Outcomes

The outcomes of this study is the determined rate at which the tide gauge deforms annually and by how much it has deformed from the last research in 2021

1.8. Thesis structure

This study contains five chapters. The first chapter introduces deformation and its major causes, rationale of the study, objectives', beneficiaries, significance and location of the study area. The second chapter contains a theoretical review of methods used to collect data, monitoring networks, geodetic reference networks, least square adjustment and some related studies around the world. Chapter three contains a full detailed explanation on the methods that were used to collect data for this study. Chapter four analyses the result of the study and a brief discussion on the result. The last chapter contains conclusion and recommendation where the research relates the output with the research objectives. In the last chapter the objectives of the study must be met unless otherwise the explanation for the failure is explained.

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CHAPTER TWO

LITERATURE REVIEW.

This chapter contains an overview about the previously published works on deformation monitoring of tide gauges and concrete structures, type of tide gauges and their operations, monitoring networks and provides a general understanding of the existing knowledge on deformation monitoring. The current knowledge including substantive findings as well as theoretical and methodological contributions to deformation monitoring of tide gauges is presented here

2.1. Overview.

Deformation refers to the changes in shape, position, or orientation of a solid body or surface relative to a reference frame. These changes can occur naturally due to weathering, erosion, or they can result from human activities such as construction, excavation etc. (David, 2006)

Deformation monitoring, also known as deformation survey involves consistently measuring and observing how applied loads cause changes in the size or shape of an object.

Deformation survey is conducted to assess if there is any motion occurring and to determine if a structure is secured and protected. Deformation monitoring is a significant aspect of recording measured data that can be utilized for various purposes such as computation, analyzing deformations, anticipating maintenance needs, and triggering alarms. The movement detected can be studied to identify if it is caused by seasonal or daily factors and importantly to predict future movements of the structure. There could be numerous reasons why such a survey is necessary. (Sofia, 2018). Deformation monitoring and analysis aids in the process of evaluating if a measured displacement is noteworthy enough to necessitate action. Statistical significance must be verified for the deformation data and then compared to predetermined thresholds to assess if the movements surpass acceptable limits. Additionally, movements below established limits must be reviewed to determine if they may indicate potential risks. Monitoring is always done on engineering structures such as Offshore platforms and rigs, railways and roads, bridges, tunnels, dams, industrial plants and factories, pipelines etc. (Ashraf, 2015)

A tide gauge is an instrument that is used to measure changes in sea level over time. It typically consists of a stilling well, a pressure sensor or float, and a data logger. The stilling well is a tube

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or pipe that is fixed to a stable structure such as a pier or foundation, and is designed to prevent waves and turbulence from affecting the water level inside the well. The pressure sensor or float is then placed inside the well and measures changes in water level relative to a fixed reference point. Tide gauges can provide data on a variety of parameters related to sea level, including tidal range, storm surge, and long-term sea level trends. This data is important for many coastal applications, including navigation, offshore construction, and coastal hazard management. Tide gauge networks are often maintained by government agencies and research institutions around the world to provide continuous monitoring of sea level changes. (NOAA, 2023)

2.2. Tide gauge and their operations

A tide gauge is a component of a modern water level monitoring station which is equipped with sensors that continuously measure the height of the water level in the surrounding area. This information is essential for various coastal activities such as safe navigation, engineering design, and sounding. It is used with computers to record water level. Tide structures are built to house permanent tide gauges. These structures contained the necessary equipment, including a stilling well and a mechanical pen-and-ink recorder, while a tide or tidal staff was attached outside. The staff served as a large measuring stick, which scientists used to manually observe tidal levels and compare them with readings taken every six minutes by the recorder. Monthly maintenance was required for tide houses and the data they recorded, where scientists would collect the data tapes and send them to headquarters for manual processing. (Vikas & Baredar, 2019)

The purpose of tidal measurements' is;

i. The observation data are used to publish tide tables including forecast values about the time of high/low water and tide levels on a daily basis
ii. Establishing the level of the lowest tide at which the chart datum is created
iii. During hydrographic survey they are used to reduce depth measurement into datum.

Types of tide gauges

Tidal observations are carried out using tide gauges. These gauges are of two types:

a. Manual recording or Visual Tide gauge b. Automatic recording.

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2.2.1. Visual tide gauge

The tide pole or visual tide scale or tide staff is the simplest and common method of measuring the rise and fall of the tide. Marked in appropriate units (usually meters and decimeters) and vertically erected as near as possible to the area of interest, the scale may be read at intervals (l0 minutes to 30 minutes depending on rate of rise or fall) to enable the tidal curve to be plotted as a graph of height against time. Since an observer is required constantly this method is usually limited in use to small surveys (Gauges & Radar, 2012)

2.2.2. Automatic recording tide gauges:

The principle of operation of an automatic recording tide gauge may be one of the following:

i. Flotation
ii. Hydrostatic pressure
iii. Acoustic
iv. Electronic/radar/GPS.

Available designs vary from simple portable recorders to one's fixed in permanent installations with automatic radio transmitting devices. Some types may be 'commanded' to sample short-period sea and swell data or tidal heights at will, others record both in turn. (Gauges & Radar, 2012)

(a). Float gauges

These consists of a vertical tube or stilling well, open to the sea through a small orifice at the bottom and in which a float sits on the water surface. A wire joins the float to a recording mechanism, and it is kept taut by a counter balance weight or sometimes a spring. By a system of gears, a pen is moved across a recorder paper as the height of tide changes. The paper is secured round a drum which is rotated by clockwork/ or electric motors and the height of tide is recorded against time. Some instruments are now available which record on magnetic tapes/discs at regular intervals, and some can transmit the data on real time via radio or satellites to a receiving station on another part of the world. (Gauges & Radar, 2012)

(b). Hydrostatic pressure tide gauges

These consists of a pressure sensitive capsule held in position underwater and connected with a

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flexible tubing to a recorder on the surface. The variation of the water level above the capsule, due to tides, is sensed by the capsule and transmitted to the recorder. The old models comprised of a rubber diaphragm, a pressure tube and a Bourdon tube which drives a pen. The recording paper is driven by a clockwork mechanism on top of the recorder. Modern pressure gauges are more compact, portable, runs on batteries and records digitally in internal memories or linked to computers. Most of these types however are for shallow water use only. There are deep water versions of pressure tide gauges which are installed on the sea bed and can record internally for some time or transmit the data to surface recorders.

(c). Acoustic tide gauges

These consists of a device which transmits sound waves and detects the reflection on the air/water or water/air boundary. Knowing the speed of sound in air/water, and the time interval from transmission of the pulse to the reception of the echo, the variation of the water level due to tides can be determined. Acoustic tide gauges are of two types: -

- Stilling well type: In this type the transmitting and receiving devices (transducer) is fixed on top of the stilling well, and the sound waves travels in the air medium and reflects on the water surface. The height measured is from the transducer to the water level. To get the depth of the water level from the seabed, the measured height should be subtracted from the height of the transducer from the sea bed.
- Sea bed type:

In this type the transducer is moored (fixed) on the sea bed, and the sound waves travels in the water medium to reflect on the water/air boundary

(d). Electronic tide gauges

These make use of the wave staff (resistance wire) whose resistance change depending upon the tide level i.e., depending upon the amount of the wire immersed in the water. The wave staff is attached to an oscillator whose frequency of oscillation at a fixed reference level is dependent to the wave staff resistance. The oscillator is coupled to a voltage recorder which convert the variable voltage readings into graphic tide recordings or direct reading of the tide heights. (Gauges & Radar, 2012)

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(e). Radar tide gauges and bubbler gauges

Radar tide gauges employ the same principles as the acoustic gauge except the signal emitted is electromagnetic signal. The height of the emitter above datum must be known. Bubbler Gauges detects the pressure required to release a stream of air bubbles. This pressure will vary with the height of water above the bubble outlet

(f). Gps buoys

These are floatation buoys that are equipped with continuously reading GPS receiver(s), and can monitor fluctuation of tides, currents and/or waves and can transmit the data in real time to receiving stations on ships or land. (Gauges & Radar, 2012)

2.3. The Tanga tide gauge

The Tanga tide gauge is a device used to measure the changes in sea level over time. It is located in Tanga, a coastal city in Tanzania, and is part of a global network of tide gauges that provides important information about sea level rise and other oceanographic phenomena.

The Tanga tide gauge works by measuring the level of the ocean surface relative to a fixed point on land, known as a benchmark. The device consists of a sensor that is submerged in the water and connected to a recording device on land. As the water level rises and falls, the sensor detects these changes and transmits the data to the recording device, which then stores the information for later analysis.

The data collected by the Tanga tide gauge is used by scientists and researchers to better understand the dynamics of the ocean and how it affects coastal communities. It can be used to track long-term trends in sea level rise, monitor the effects of storms and other weather events, and help predict future changes in sea level that could impact the environment and human populations.

Overall, the Tanga tide gauge is an important tool for studying the ocean and its interactions with the planet, and plays a crucial role in our understanding of climate change and its potential impacts on the coastlines.

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2.4. Geodetic fixing of TGBM

In order to establish a network of tide gauge benchmarks for sea level monitoring purposes, it is necessary to precisely coordinate the stations that will make up the fiducial network in a global reference frame. Earlier, first order geodetic spirit levelling with an accuracy of about 1mm or 2mm over few kilometers is used annually to compute the elevation of these stations and it is suitable to detect any vertical land movements of the tide gauge benchmarks with respect to the local benchmarks. However, spirit levelling is affected by significant systematic errors over very long distances. The advancement in modern geodetic techniques has given rise to more advanced methods including the space techniques including the GPS, VLBI and SLR. The GPS stations were co-located with absolute gravity measurements and precise spirit leveling to monitor any vertical crustal movement, allowing the signals from the tide gauges to be differentiated from other tectonic phenomena. To achieve this, various techniques and procedures are employed to eliminate measurement errors associated with GPS observations, such as satellite and receiver oscillator offset and drift, propagation media effects, initial phase ambiguity and cycle slips, observation time-tag errors, and multipath. Precise determination of GPS satellite orbit is required, which is perturbed by various gravitational and non-gravitational forces. The task uses suitable ITRF/ reference frames, which are realized through a global set of VLBI and SLR determined station coordinates, and closely followed the IERS recommended computation standards. The station positions are subjected to movement due to tectonic plate motion, solid Earth tide loading, ocean tide loading, and atmospheric loading. (Govind & Ramesh , 1994)

2.4.1. Deformation monitoring

Deformation monitoring requires investigating either a displacement is taking place or not and at what velocity per year. It also gives a room to assess if the displacement that has been measured is significant enough to take an appropriate action. The data on deformations needs to be analyzed through statistical tests and then compared against specified limits. If movements fall below these limits, it is necessary to examine whether they may still indicate potential risks. To carry out deformation analysis, software is used to collect data from sensors, compute meaningful values, and record results. If a threshold value is exceeded, responsible parties may be alerted. However, the ultimate decision on how to respond to the movement must be made by

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a human operator. This could involve additional verification through on-site inspections, reactive measures like structural repairs, or emergency responses such as shutting down processes, implementing containment procedures, or evacuating the site. Deformation monitoring may be conducted by two techniques either geodetic or non-geodetic

2.4.2. Geodetic technique

The geodetic technique involves photogrammetric (aerial, digital and terrestrial photogrammetry), satellite (such as Interferometric Synthetic Aperture Radar-InSAR and Global Positioning System- GPS) and conventional (terrestrial such as precise levelling measurements, angle and distance observations etc.).

Table 2.1Geodetic monitoring methods and their corresponding instruments

Geodetic method	Instruments
Satellite base survey	GPS, GALILEO Receivers and GLONASS
Laser scanner technique	Laser scanner
Interferometry SAR image	SAR image processing/computer
Precise geometric levelling	Precise levelling instrument
Precise trigonometric levelling	Precise theodolite and EDM
Alignment survey	Theodolite, laser optic etc.
Conventional survey	Theodolite and EDM measurement instruments

The geodetic technique is the most common method of monitoring engineering structures which uses instruments as analyzed in the table above. Instruments like digital levels, total stations, and Global Positioning System (GPS) to measure vertical and horizontal displacement. The choice of monitoring method depends on the required accuracy for the survey. The accuracy of the monitoring method used is critical to ensuring the detection of any movement under normal operating conditions.

2.4.3. Non geodetic techniques / geotechnical methods.

Detecting movement or displacement in structural objects is a critical aspect of deformation monitoring, and it can also be done by non-geodetic methods. The geotechnical methods may

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involve instruments like inclinometer, extensometer, joint meter, crack meter, reserved pendulum and settlement column and many others as shown below. (Kalkan & Bilgi , 2012)

Table 2.2. Non geodetic method and their corresponding instruments

Non geodetic method	Instrument
Crack measurement	Crack meter
Vertical displacement measurement	Reserved pendulum
Grouting measurement	Joint meter
Pore water measurement	Piezometer
Length change measurement	Extensometer
Displacement measurement	Settlement column
Slope measurement	Extensometer

The methods and instrument used in this dissertation are for geodetic technique

2.5 Computing the displacement magnitude

The displacement of the object points in the beam structure of the tide gauge is computed as the difference in coordinates between the two epochs which is given by the relationship below;

$$E_J^{K+1} - E_I^K = DE \quad \textbf{2.1}$$

$$N_J^{K+1} - N_I^K = DN \quad \textbf{2.2}$$

$$H_J^{K+1} - H_I^K = DH \quad \textbf{2.3}$$

Whereby;

E_j^{k+1}, N_j^{k+1}, and H_j^{k+1} are coordinates of the last epoch

E_i^k, N_i^k, and H_i^k are coordinates of the current epoch (Diego & Brendan, 2015)

2.5.1 Deformation analysis

Analyzing the deformations and movements of structures is essential to determine whether significant movement has occurred between observation epochs. To determine the displacement, the point’s displacement is computed to the corresponding 95% confidence interval.

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If the magnitude of the displacement of point J is classified as Dj and the maximum dimension of combined 95% confidence ellipse for j is described as Ej, then if Dj<Ej we can conclude that no n significant deformation has occurred in point j but rather the difference observed is influenced by measurement errors. On the other hand, if Dj>Ej, then we conclude that point movement or deformation has occurred in point E.

The magnitude of displacements Dj an Ej are computed as;

$$D_J = \sqrt{(dN^2 + dE^2)} \quad 2.4$$

$$dE = C_P\sqrt{(M)} \quad 2.5$$

AND $M = (m_J^{K+1})^2 + (m_J^K)^2$ **2.6**

Whereby;

$(m_j^{k+1})^2$ = standard error in position for the K+1 epoch and

$(m_j^k)^2$= Standard error for the position in the previous epoch

2.6. A geodetic control network

A geodetic control network (also geodetic network, reference network, control point network, or control network) is a network frame or wire frame on which continuous and consistent mapping and surveys are based. It is a network often of triangles, which are measured precisely by techniques of control surveying, such as terrestrial surveying or satellite geodesy. A geodetic control network consists of stable, identifiable points with published datum values derived from observations that tie the points together. Classically, a control is divided into horizontal (X-Y) and vertical (Z) controls (components of the control), however with the advent of satellite navigation systems, GPS in particular, this division is becoming obsolete. The higher-order network of control points is normally defined in both space and time using global or space techniques, and are used for lower-order points to be tied into. The lower-order control points are normally used for engineering, construction and navigation. (Fgnievinski, 2023)

2.7. Absolute monitoring network

This type of a monitoring network is mainly for monitoring small scale engineering structures like bridges, tall buildings etc. The network is divided into two parts which are reference points designed outside of the structure and the object points which are designed on the deformable

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structure. The most disadvantage of this network type is that movement of reference points may affect the object points on the structure being monitored. Figure 2.1 shows the absolute network

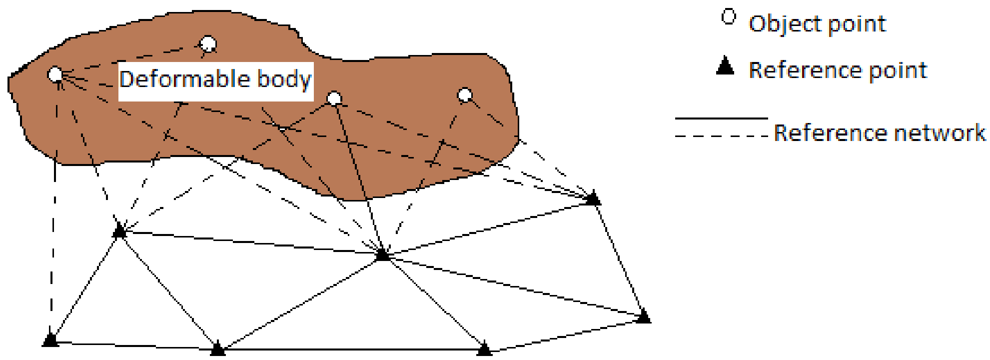

Figure 2.1. Absolute monitoring network (Setan, 2023).

2.7.1. Relative monitoring network

This type of network has all geodetic points moving with the structure to be monitored. This is the most efficient method as it can cover large structures and the individual points cannot affect the deformed structure. Figure 2.2 shows relative monitoring structure

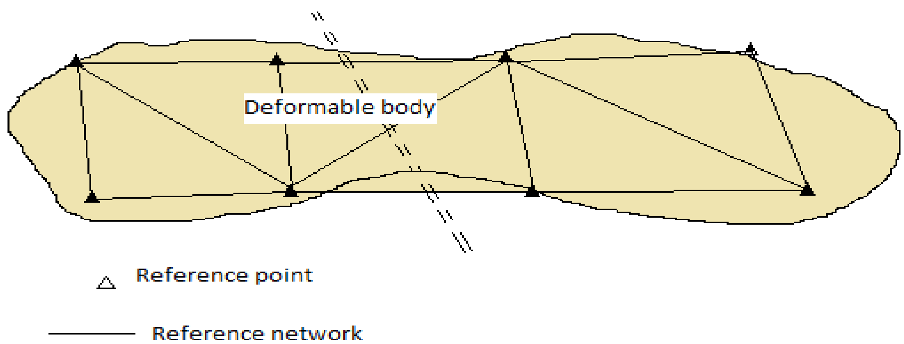

Figure 2.2. Relative monitoring network (Setan, 2023).

2.8. Related monitoring studies

Using Total Station for monitoring the deformation of high strength concrete beams; A scientific study conducted by (Eteje *et al*, 2008), was done to compare the accuracy of DGPS and total station methods in monitoring the static deformation of engineering structures, specifically the

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Palm House in Benin City. In this study DGPS was used to determine the roof monitoring points' rectangular coordinates and total station to determine the 10th-floor base monitoring points' rectangular coordinates, bearings, and distances from the reference stations. The observations were carried out at six epochs over eighteen months, and the results showed that neither the 10th floor nor the entire building underwent any movement during the monitoring period. This study recommended the use of the DGPS method for monitoring engineering structures. Another related study by (Ashraf *et al*, 2008) investigated an integrated monitoring system for estimating the deformation behavior of high strength concrete beams. The study presented two surveying techniques (one and two total stations measurement techniques) to evaluate the deformation behavior of structural members and compared the results with those obtained using structural techniques

Structural Deformation Monitoring Surveys of New Administrative Building of Federal School of Surveying; the purpose of structural monitoring is to enhance the safety conditions of buildings and prevent cases of building collapse. Geodetic measuring techniques are used during the survey, and the type of structure, environmental conditions, and expected accuracy of measurements are considered when determining the appropriate technique to use. Different structural monitoring methods require specific techniques, such as precise levelling measurements, angle and distance measurements, terrestrial, aerial, and digital photogrammetry, GPS, and other specialized techniques. In this study, deformation monitoring was done using geodetic survey instrumentation by professionals in Nigeria.

The control network points were positioned using GPS measuring technique for both new and existing pillars and height differences were supported with precise leveling measurements; and total Station equipment for angular observations which employed intersection method. Afterward, deformation analysis using the height differences according to provided data from the GPS and the precise levelling were carried out separately. The result of the analyses shows that the building is stable both horizontally and vertically, and there were no noticeable displacement on the structure; as such it is safe to dwell in it. (Abdullahi & Yelwa, 2016)

Measuring the dynamic deformation of bridges using a total station; this study conducted at the University of Nottingham is concentrated on the dynamic deformation of structures, in particular bridges. It is well known that long term movements of structures can be monitored using a total

`

station. Measurements are taken over minutes, hours or weeks to a number of targets to measure settlement or long-term permanent deformations. Monitoring equipment included GPS, accelerometers, pseudo files and the total stations. A recent bridge trial conducted by the authors on the Wilford Suspension Bridge in Nottingham included the use of a servo driven Leica TCA2003 total station measuring angles and distances at a 1 Hz data rate. The total station coordinate results were compared to the GPS data. Outlined in this paper are the results from initial total station trials, including the bridge trial (Emily & Alan , 2003)

Monitoring and analysis of vertical and horizontal deformations of a large structure using conventional geodetic techniques; to ensure the safety of large engineering structures, monitoring their deformations is crucial as several factors can affect them. The purpose of this study was to determine the structural integrity of Palm House Building in Benin City by monitoring and analyzing its vertical and horizontal deformations. To achieve this, two conventional geodetic techniques, digital level and total station, were used, along with four reference stations and two sets of monitoring points. The positions and heights of the reference stations were determined using CHC900 dual frequency GNSS receivers and digital level with respect to nearby control station and benchmark. The observations of the monitoring points were taken at three epochs with an interval of six months and were adjusted with least squares technique to determine their accuracy and reliability. The computed displacement magnitudes were compared with their respective 95% confidence ellipses/intervals to identify any significant movement. The study concludes that the structure was stable during the monitoring period. (Matthew, 2018)

Geodetic network establishment for monitoring the Tanga tide gauge platform (Leonard, 2018)

The Tanga tide gauge concrete structure was monitored using a deformation geodetic network. GPS observations were conducted to establish stable monitoring points on the structure, as well as reference control points on the stable ground. However, due to limitations of GPS static observation, angle and distance observations were used to fix deforming points on the structure. A network consisting of six points was established, including three object points on the structure and three control points on the stable ground. This network design is an absolute network. Three monitoring points were observed using GPS static technique, while the object points on the structure were fixed using tachometry. It is possible that the network design on the tide gauge established (Leonard, 2018) has been deformed due to various factors such as the weight of the

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structure and the effect of tidal ocean loading. Figure 2.1 below shows the monitoring network of the Tanga tide gauge with reference points and object points.

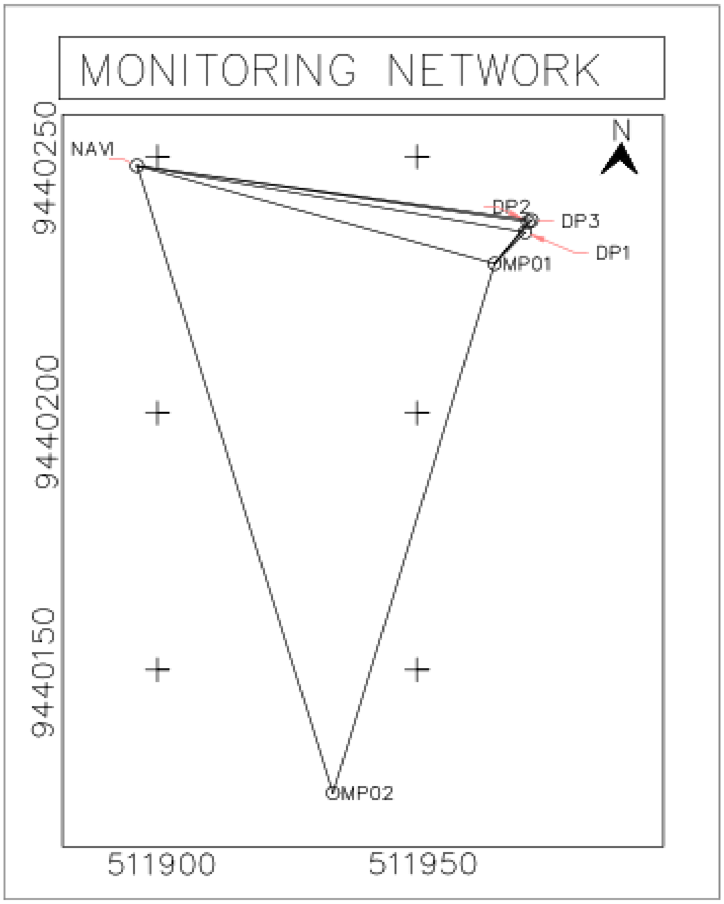

Figure 2.3. Deformation monitoring network of Tanga tide gauge

2.9 Least square adjustment by parametric model

The parametric model relates the adjusted observations (L) with some unknown parameter (x). It is symbolically represented as L=f (x). In this model, each of the measurements will produce one equation involving some or all of the specified parameters with no other observations involved in the equation. The parametric equations are formulated so that when approximate value of the unknown parameters are substituted into the equations, the derived or calculated observations and the derived observations are the misclosures. (Ogundare, 2019)

The redundancy of parametric model equation or the number of degree of freedom of an adjustment is determined as the number of model equations formed minus the number of

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unknown parameters involved in the equations. Since the number of parametric model equations is always the same as the number of observations, the number of degrees of freedom can also be determined as the number of observations minus the number of unknown parameters. The typical quantities measured in surveying are slopes, angles, azimuths, coordinate difference and elevation differences. (Ogundare, 2019)

2.9.1 Elevation difference observable

The elevation difference measurement between point A and B (Δh_{AB}) produces the equation

$\Delta h_{AB} = h_B - hA$ 2.7

based on differential levelling

h_B and h_A are heights of point A and B above a given datum(WGS 84) respectively

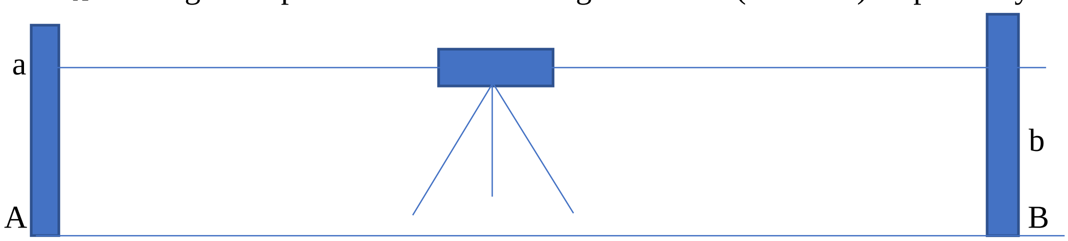

Figure 2.4. Elevation difference observation between two points

The functional relationship between the adjusted observations and the adjusted parameters is given as La= f(Xa). Where La = adjusted vector of observations and Xa= adjusted station coordinates. Equation (1) is linear function and the general observation equation model was obtained. To make the matrix expression for performing least squares adjustment, analogy will be made with the systematic procedures. The system of observation equations is presented by matrix notation as: V= AX-L 2.8

Where,

A = Design Matrix

X = Vector of Unknowns

L = Calculated Values (lo) Minus Observed Values (lb)

`

V = Residual Matrix

$$\begin{array}{cccc} V & A & X & L \\ \begin{pmatrix} V1 \\ V2 \\ \dots \\ Vm \end{pmatrix} = & \begin{pmatrix} a11 & a12 & \dots & a1n \\ a21 & a22 & \dots & a2n \\ \dots & \dots & \dots & \dots \\ am1 & am2 & \dots & amn \end{pmatrix} & \begin{pmatrix} x1 \\ x2 \\ \dots \\ xn \end{pmatrix} - & \begin{pmatrix} l1 \\ l2 \\ \dots \\ lm \end{pmatrix} \end{array} \quad 2.9$$

Estimated parameter

$X = (N)^{-1}(t)$

Where

N = (ATPA) = Normal Matrix

T = (ATPL)

$N^{-1} = (ATPA)^{-1}$

$X = (ATPA)^{-1}(ATPL)$

P = weighted matrix

The models for the computation of a posteriori variance and a posteriori standard error was

Computed by;

A Posterior variance $\delta_o^2 = V^TPV/n\text{-}u$ 2.10

A Posterior standard error $\delta_o = \sqrt{}\ (= V^TPV/n\text{-}u)$ 2.11

`

CHAPTER THREE

METHODOLOGY.

This chapter includes all methods and practical procedures that were used in this dissertation to obtain data (horizontal coordinates and elevation) that is used to assess the deformation of the tide gauge concrete structure. Figure 3.1 below shows the sequence of stages from data collection, data processing, data analysis to presentation. Figure 3.1 below illustrates the workflow of the adopted methodology

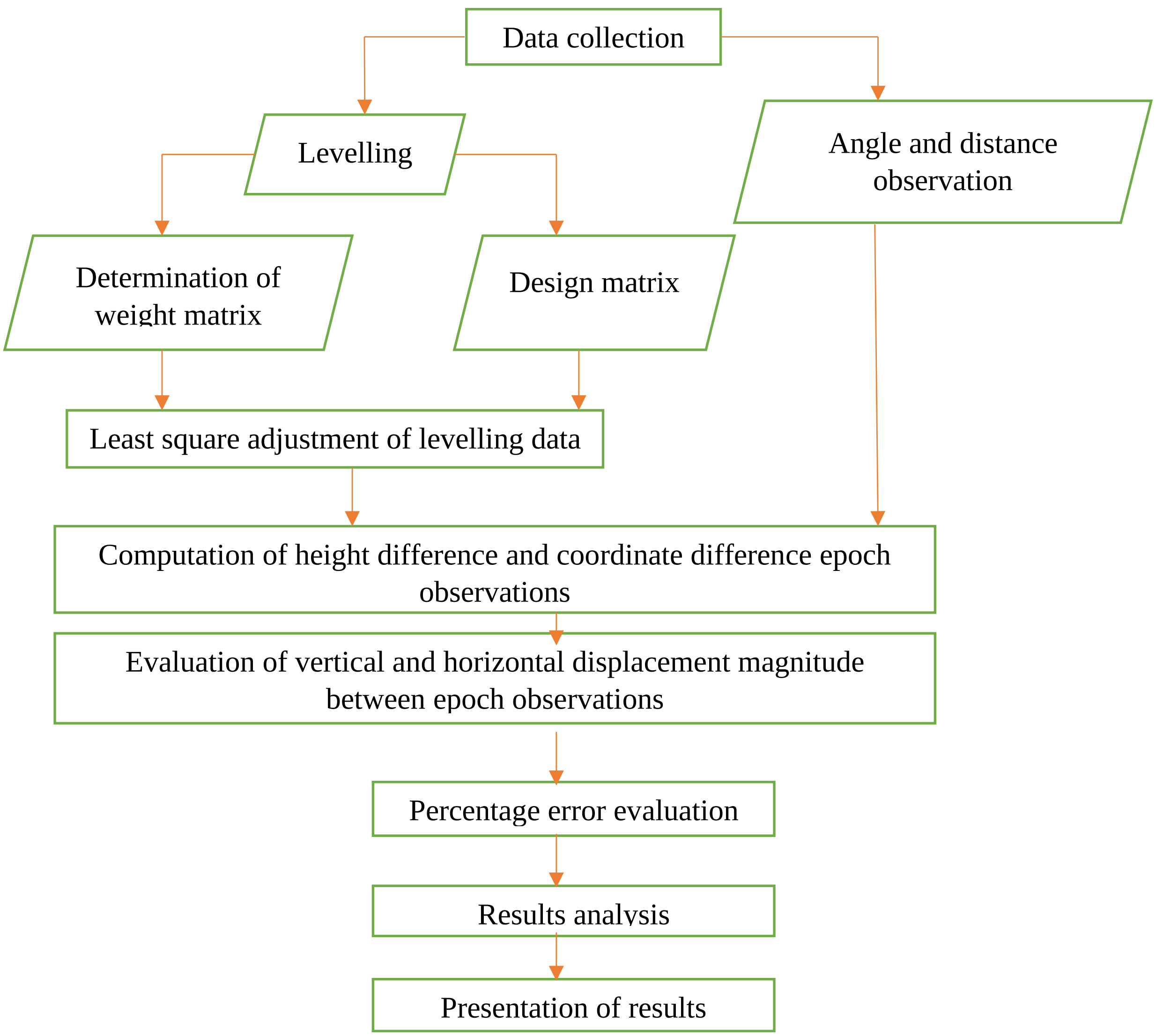

Figure 3.2.The flowchart of the adopted methodology

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3.1 Data collection

3.1.1 Reconnaissance

This is an initial planning stage which involves preliminary examination or exploration of an area to gather information about its physical, terrain and environmental characteristics. This process involves gathering data on terrain, vegetation, water bodies and other features that may affect the surveying work. The purpose is to identify potential problems and challenges that may arise during the surveying process and to plan accordingly. It helps to ensure that the surveying work is efficient, accurate and safe from errors

Reconnaissance started by visiting the site at Tanga port and identifying the control points that were used as fiducial points of this study. The control points PCD (Preserved Chart Datum), BM01, BM2016/2017 (National Hydrographic Service) and NAVI with elevations 5.629m, 5.117m, 5.154m consecutively were identified from the port engineer office.

3.1.2 Pre-analysis and maximum expected error derivation.

Pre-Analysis refers to the initial steps taken before conducting a survey. It involves selecting appropriate surveying methods and instrumentation, observation procedures and defining the surveying objectives. It helps in overall designing of the project and to ensure the data collected is reliable, accurate and valid, and to identify the potential sources of bias and errors in the surveying work and to make necessary adjustments before conducting the actual survey. In this research, pre analysis based on the instrument's user manual derived by the manufacturer for both levelling and distance and angle observation. The instruments used in pre analysis are NIKON AP-08 total station and SOKKIA automatic level.

3.1.3 Survey tolerance limit.

This is the acceptable amount of error or deviation in survey measurements. It is the maximum allowable difference between the measured value and the true value of a parameter. The tolerance limit varies depending on the type of survey and the specific measurement being taken. During pre-analysis, the most commonly used uncertainty for survey tolerance is at a probability of 99.7% or α= 0.003. The survey tolerance or maximum error accepted can be given as 3(SE) where SE is the standard error of the measurement. The accuracy in monitoring surveys is determined by both measuring procedures and performance of the instrument. Through network

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pre analysis, expected error and positioning confidence for all points in the monitoring can be estimated. Therefore, both the NIKON N total station and the Sokkia automatic level were examined to get maximum expected error for deformation analysis.

i. NIKON N Total station

The expected standard deviation on determining position using total station Nikon N, from its specifications, are δ_{β}= 2´´ and δ_{d} = 1mm + 1.5ppm

Recall

$$\delta = \sqrt{(\delta_{\beta}^2 + \delta_{d}^2)}$$

Where

δ- Expected standard deviation on determining horizontal position using total station

δ_{β} – Standard deviation in angle (horizontal and vertical) measurement

δ_{d}- expected error in distance measurement

Converting (δβ=2'') to mm:

$$= (\pi \times 1)/ (60 \times 60 \times 180)$$

$$\underline{\delta_{\beta}^2 = 9.401772 \times 10^{-11} \text{ mm}}$$

$$\delta_{d} = 1\text{mm} + 1.5\text{ppm}$$

$$\delta_{d} = 1\text{mm} + (1.5 \times 11.069) / (1000000)$$

$$\underline{\delta_{d}^2 = 1.033565\text{mm}}$$

$$\delta = \sqrt{(\delta_{\beta}^2 + \delta_{d}^2)}$$

$$\delta = \sqrt{(9.401772 \times 10^{-11} \text{ mm} + 1.033565\text{mm})}$$

$$\delta = 1\text{mm}$$

The maximum allowable error in determining horizontal position using total station is 1mm.

`

ii. SOKKIA Automatic level

From the instrument's specifications, the standard deviation (accuracy) in determining the difference in elevation of a levelling line is 1.5mm for a 1km loop. For height difference between two points is given by equation 2.7

For known height H_A(Constant), then $\delta_B^2 = \delta_{\Delta hAB}$ 3.1

3.1.4 Two peg test

Two peg test is carried out to eliminate collimation error and to check if the line of sight is horizontal. It was performed in such a way that two pegs are placed 60m apart and the dumpy level set intermediate between two pegs. The first reading was then recorded at point A and on point B consecutively. Since the level is intermediate, then for any possible errors which may cause the line of sight not to be horizontal on both staffs A and B are identical. The level is then moved near to peg A just 5m away and then the staff readings are taken on both staffs.

The level is then moved close to point A 5m away and readings are taken on both staffs A and B. For staff A is very close to the level, then any error due to this short distance is negligible. Figure 3.1 shows setup of two peg test.

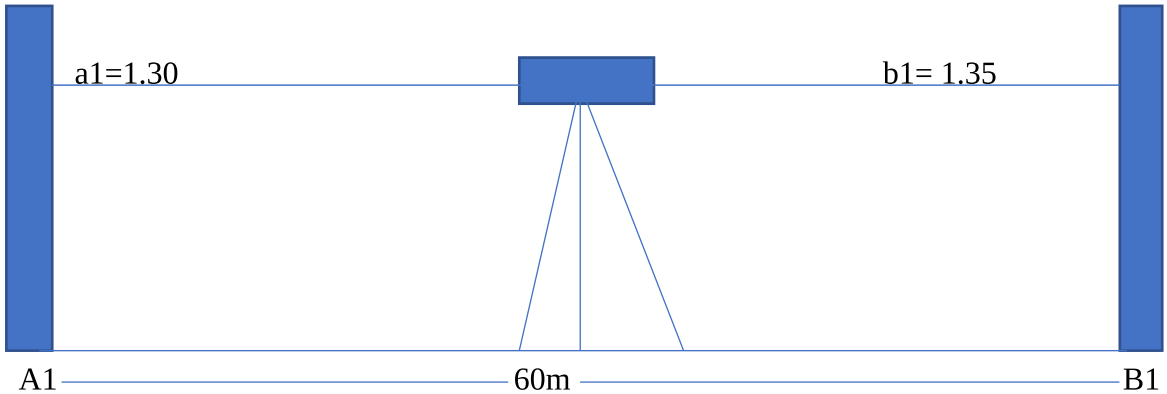

Figure 3.1. Setup of two peg test

The level is then setup close to point A (5m) and readings are then taken on both staffs A and B and since the distance from A is very small, then any staff reading error introduced her in this very short sight is insignificant. Figure 3.2 illustrates the procedures of two peg test by moving the level machine near staff A

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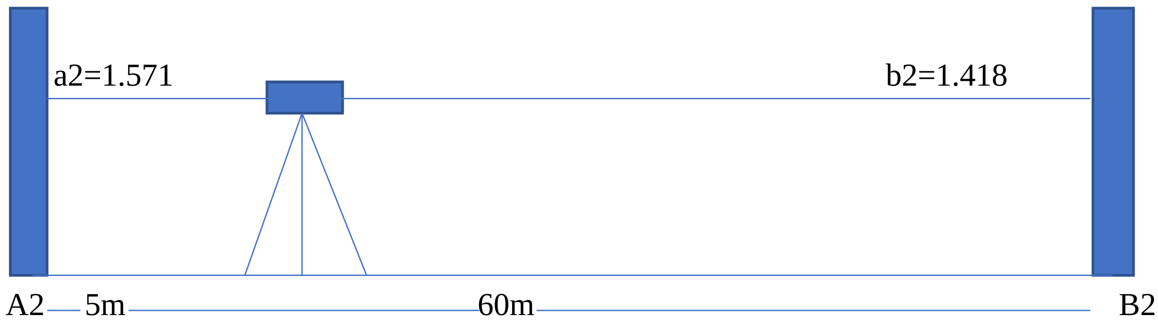

Figure 3.2. Level is setup close to point A

Mathematical models

$\Delta h1= (a1+e) – (b1+e)$

$\Delta h1= a1-b1$……………………………………………… i

$\Delta h2= a2-b2$………………………………………………. ii

But $\Delta h1=\Delta h2$

·: eqn1=eqn2

The magnitude of collimation error is given as

e= (a1-a2) + (b1+b2)

= (1.30-1.575) + (1.35-1.418)

E=0.01m

3.1.5 Levelling to obtain height of object point.

The vertical measurements in this study will base on the benchmark BM01 with height 5.117m. Levelling will be carried out in a loop to obtain the orthometric height of object points DP1, DP2, DP3, DP4, DP5, DP6 and DP7. The levelling procedures will start at BM01 with known height and commence to the aforementioned stations and closed back to BM01. The obtained leveling data will be processed by Least squares adjustment to compute the height differences between epoch observations

`

3.1.6 Tachometry observation

The control points NAVI and MP01t were used to coordinate the object points inserted on the beam of the tide gauge concrete structure using a total station. Planimetric 2D coordinates will be obtained by bearing and distance fixation. The figure 3.3 below shows tachometric observation

Figure 3.3 Tachometry observation

Observation procedures

I. Datum check and check distance was done using the control points NAVI and MPO1
II. After datum check, the total station is used to measure the object points to obtain the bearing and distances and finally the coordinates in two dimensions will be obtained

`

CHAPTER FOUR

RESULTS AND ANALYSIS.

This chapter contains a discussion analysis of the results of this research including assessment of the misclosure and comparison of these results with the previous ones. The value of the levelling misclosure may vary based on the sequence of the levelling network. Typically, levelling can be either loop or tied to benchmark that is known. The assessment of the misclosure is dependent on both the order of the network and the network distance in kilometers m, which varies from 2mm for precise levelling to 12mm or more for engineering survey. For this particular study, the loop's total distance was 0.2251km and it was a first order levelling network. In this scenario the allowable misclosure is, 423 mm. However, the resulting misclosure of 1mm indicates that the outcome represents an upper bound estimate and can be utilized for deformation analysis.

4.1 Result of levelling adjustment

Least squares adjustment technique was used to adjust the network to obtain vertical position of object point and its accuracy. Table 4.1 show the observed height difference and the distance between levelling points.

Table 4.1 Length of line and different in height between point.

Line	From-To.	Observed h (m).	Length of line (km)
1	NAVI-PCD	-0.382	0.057
2	PCD-DP6	1.017	0.008
3	DP6-DP1	-0.003	0.0015
4	DP1-DP7	0.006.	0.002
5	DP7-DP5	-0.006	0.00
6	DP5-DP2	0.07	0.0015
7	DP2-DP4	0.011	-0.0008
8	DP4-PCD	-1.033	0.009
9	PCD-DP1	1.015	0.008
10	DP1-DP6	0.003	0.001
11	DP6- DP7	0.003	0.0015
12	DP7-DP5	-0.005	0.002

`

13	DP5-DP2	0.006	0.0015
14	DP2 - DP4	0.011	0.001
15	DP4-PCD	-1.033	0.01
16	PCD-NAVI	0.383	0.057
17	DPI-PCD	-1.014	0.01
18	DP6-DP1	-0.003	0.001
19	DP7-DP6	-0.003	0.0015
20	DP5- DP7	0.006	0.002
21	DP2-DP5	-0.007	0.001
22	DP4-DP2	-0.011	0.0005
23	DP3-DP4	-3.015	0.004
24	DP1-DP3	3.033	0.005
25	DP7-DP 1	-0.006	0.002
26.	DP5-DP7	0.006	0.002
27	DP2-DP5	-0.007	0.0018
28	DP4-DP2	0.0005	0.011
29	DP6-DP4	0.002	0.015
30	PCD-DP6	1.018	0.01

The residual or standard deviation to approximate elevations is given by;

$\delta = -(A^TPA)^{-1}A^TPW$ 4.1

Where

A – First design matrix

W- Misclosure matrix

P- Weight matrix

Adjusted parameters/ levels are given by $X = X_0 + \delta$ 4.2

By using MATLAB, the adjusted elevations were obtained as shown on table below

`

Table 4.2 Adjusted levelling data

S/N	Station	Reduced Level (m)	Standard deviation/Residuals (m)
1	DP1	4.5223	0.00027
2	DP2	4.5151	0.00029
3	DP3	1.4894	0.00041
4	DP 4	4.6043	0.00088
5	DP5	4.5220	0.0009
6	DP6	4.5194	0.000026
7	DP7	4.5162	0.000280

4.1 Statistical testing for blunders

The Baard's concept global test is used to test for blunder and it estimates the standard deviation from parametric adjustment of the leveling network. The hypothesis for the Baard's global test is formulated as

$$H_o; s^2_o = \sigma^2 \text{ against HA}; s^2_o > \sigma^2 \qquad 4.3$$

Which is a single tailed test. The statistical test used by Baarda to check failure on the upper end is as follows ;($(df)x\ s^2_{o)/}\ (\sigma^2_{o)} < \lambda^2_{1-\alpha,\ df}$ 4.4

The null hypothesis for the above test is for the absence of blunders in observations and the obtained posteriori variance factor of unit weight of levelling is $s^2_o = 4.3426x\ 10E\text{-}5$

$$((df)x\ s^2_{o)/}\ (\sigma^2_o < \lambda^2_{1-\alpha,\ df}$$

$$((23x4.3426x\ 10E\text{-}5)/\ \sigma^2_o < \lambda^2_{0.005,23}$$

$$((23x4.3426x\ 10E\text{-}5)/\ 1 < 35.172$$

$$9.98798x10E\text{-}4 < 35.172$$

At 95% confidence interval, the hypothesis $s^2_o = 4.3426x\ 10E\text{-}5$ is statistically equal to σ^2_o=1. The global test has then passed and the measurement is free from errors

`

4.2 Results comparison

In order to assess any the deformation of a structure, there are must be at least two epochs two epochs observed at a specific time interval in order to compute the displacement magnitude. The displacement magnitude is computed by subtracting the recent position from the previous position of the last epoch

Mathematically;

$$\text{Magnitude} = P_{\text{current epoch}} - P_{\text{previous epoch}} \qquad 4.5$$

Where the previous epoch consists of measurements recorded in 2021.

Table 4.3 Comparison of levelling data for epoch one and two

Station	Reduced Level in Epoch 2 (2021) m	Reduced Level in Epoch 3 (2023) m	Displacement (mm)
DP1	4.5224	4.526	3.6
DP2	4.5153	4.5194	4.1
DP3	1.4993	1.5051	5.8
DP4	4.5043	4.5113	7
DP5	4.5221	4.5241	2
DP6	4.5194	4.5212	1.8
DP7	4.5163	4.5235	7.2

4.3 Analysis of vertical deformation

The measurement (reduced levels) obtained are then tested if they are significant to investigate the deformation through comparison of the magnitude of the calculated difference in elevation with percentage confidence in vertical deformation

4.3.1. Percentage confidence in vertical deformation (e_n)

The percentage confidence in vertical deformation (e_n) is given by; $e_n = C_p \sqrt{(\delta_c^2+\delta_p^2)}$ 4.6

`

Where C_p is a corresponding value in a specific confidence interval, δ_c is a standard error in position for the current epoch observations and δ_p is a standard error in position for the previous epoch.

Magnitude of difference (D_v) in vertical measurement

The magnitude is given by $D_v = \sqrt{(\Delta h^2)}$ 4.7

Interpretation

Null hypothesis (Ho); $D_{v<}$ e_n. (Point is stable)

Alternative hypothesis; $D_{v>}$ e_n. (Point is deforming)

For any point where the magnitude of difference in vertical deformation is greater than the percentage confidence in the vertical movement, then the point is considered not stable and further investigation is required to confirm it is deforming

Testing at 95% confidence interval

From the adjustment results, the standard errors are obtained and the percentage confidence can be obtained by equation 4.4

Table 4.4. Standard error of object points and their percentage confidence error.

STN	Current standard error (δ_c^2) mm^2	Previous standard error (δ_p^2) mm^2	Percentage confidence (mm)
DP1	0.0729	0.0727	0.7478
DP2	0.0841	0.0822	0.799
DP3	0.1681	0.1643	1.130
DP4	0.7744	0.7742	2.439
DP5	0.81	0.79	2.479
DP6	0.00067	0.016	0.253
DP7	0.0784	0.02	0.614

For DP1 (e_n=0.7479)

Magnitude of vertical displacement; $D_v = \sqrt{(\Delta h^2)} = \sqrt{(3.6)^2} = 3.6$mm

`

$D_v > e_n$

3.6mm > 0.7479mm

Deformation rate per year= 3.6/2= 1.8mm/year

Since the magnitude of vertical displacement for point DP1 is greater than the percentage confidence, then it is deforming at the rate of 1.8mm/year.

FOR DP2 (e_n=0.799)

$D_v = \sqrt{(4.1)^2} = 4.1$mm

$D_v > e_n$

4.1mm > 0.799mm

Deformation rate per year= 4.1/2= 2.1mm/year

Since the magnitude of vertical displacement for point DP2 is greater than the percentage confidence, then it is deforming at the rate of 2.1mm/year.

For DP3 (e_n=1.130)

$D_v = \sqrt{(5.8)^2} = 5.8$mm

$D_v > e_n$

5.8mm > 1.130mm

Deformation rate per year= 5.8/2= 2.9mm/year

Since the magnitude of vertical displacement for point DP3 is greater than the percentage confidence, then it is deforming at the rate of 2.9mm/year.

For DP4 (e_n=2.439)

$D_v = \sqrt{(7)^2} = 7$mm

$D_v > e_n$

7mm > 2.439mm

`

Deformation rate per year= 7/2= 3.5mm/year

Since the magnitude of vertical displacement for point DP4 is greater than the percentage confidence, then it is deforming at the rate of 3.5mm/year.

For DP5 (e_n=2.479)

$D_v = \sqrt{(2)^2} = 2mm$

$D_v > e_n$

2mm < 2.439mm

Since the magnitude of vertical displacement for point DP5 is less than the percentage confidence, then it is not deforming vertically.

For DP6 (e_n=0.253)

$D_v = \sqrt{(1.8)^2} = 1.8mm$

$D_v > e_n$

1.8mm > 0.253mm

Deformation rate per year= 1.8/2= 0.9mm/year

Since the magnitude of vertical displacement for point DP6 is greater than the percentage confidence, then it is deforming at the rate of 0.9mm/year.

For DP7 (e_n=0.614)

$D_v = \sqrt{(7.2)^2} = 7.2mm$

$D_v > e_n$

7.2mm > 0.614mm

Deformation rate per year= 7.2mm/2= 3.6mm/year

Since the magnitude of vertical displacement for point DP7 is greater than the percentage confidence, then it is deforming at the rate of 3.6mm/year.

4.4 Horizontal deformation.

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Datum check was conducted with the instrument at MP01 with orientation to NAVI and the result of datum check were in acceptable limit.

After datum check was done, the object points on the concrete structure were observed with a total station and their coordinates in WGS 84 ellipsoid coordinate system were obtained which defined their horizontal position. The coordinates are shown on the page below

Table 4.5 Tachometry data

STN	NORTHING	EASTING
DP1	9440244.570	511972.253
DP2	9440246.723	511971.752
DP3	9440246.910	5119973.520
DP4	9440248.725	511971.767
DP5	9440244.707	511970.790
DP6	9440249.787	511972.854
DP7	9440249.723	511973.753

4.4. Horizontal deformation analysis.

The displacement magnitude is given by $D_h = \sqrt{(\Delta N^2 + \Delta E^2)}$. 4.8

Where ΔN is the difference in north coordinates from two epoch's observation and ΔE is the difference in east coordinates of the two observation epochs. To assess the deformation, the relation $D_h < e_n$ is used where by D_h is the magnitude of the horizontal displacement of the point and e_n is the percentage maximum dimension of the combined 95% confidence interval.

Testing at 95% confidence interval

$e_n = C_p \sqrt{(\delta_c^2 + \delta_p^2)}$

From pre analysis results for total station, δ_c= 2mm and δ_p= 1mm, C_p=1.96

$e_n = 1.96 \sqrt{(2^2+1^2)} = 4.3826$mm

The percentage confidence in horizontal deformation is 4.382mm

`

Comparison of tachometry data of 2021 and 2023 and the coordinates are in WGS 84 ellipsoid coordinate system as shown on table 4.5

Table 4.6 Comparison of tachometry data 0f 2021 and 2023

STN	Coordinates of 2021		Coordinates of 2023		Difference		Displacement Mm
	NORTHING	EASTING	NORTHING	EASTING	ΔN	ΔE	
DP1	9440244.567	511972.256	9440244.568	511972.255	0.001	-0.001	1.414
DP2	9440246.725	511971.756	9440246.727	511971.755	0.002	-0.001	2.236
DP3	9440246.913	511973.517	9440246.914	5119973.515	-0.001	0.002	2.236
DP4	9440248.723	511971.767	9440248.725	511971.767	0.002	0	2
DP5	9440244.706	511970.787	9440244.708	511970.789	0.002	0.002	2.828
DP6	9440249.786	511972.857	9440249.785	511972.856	-0.001	-0.001	1.414
DP7	9440249.720	511973.757	9440249.723	511973.718	0.003	-0.002	3.605

For point DP1 (e_n= 4.3826mm)

Magnitude of maximum displacement, D_v= $\sqrt{}$ (1^2 +1^2) = 1.414mm

Since $D_v< e_n$ (1.414mm. < 4.3826mm)

Then the horizontal deformation does not exceed the expected error bound, therefore DP1 is not deforming horizontally

For point DP2 (e_n= 4.3826mm)

D_v= $\sqrt{}$ (1^2 +1^2) = 2.236mm

Since $D_v< e_n$ (2.236mm. < 4.3826mm)

Then the horizontal deformation does not exceed the expected error bound, therefore DP2 is not deforming horizontally

For point DP3 (e_n= 4.3826mm)

D_v= $\sqrt{}$ (2^2 +1^2) = 2.236mm

Since $D_v< e_n$ (2.236mm. < 4.3826mm)

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Then the horizontal deformation does not exceed the expected error bound, therefore DP3 is not deforming horizontally

For point DP4 (e_n= 4.3826mm)

$D_v = \sqrt{(2^2 + 0^2)} = 2mm$

Since $D_v < e_n$ (2mm. < 4.3826mm)

Then the horizontal deformation does not exceed the expected error bound, therefore DP4 is not deforming horizontally

For point DP5 (e_n= 4.3826mm)

$D_v = \sqrt{(2^2 + 2^2)} = 2{,}828mm$

Since $D_v < e_n$ (2.828mm. < 4.3826mm)

Then the horizontal deformation does not exceed the expected error bound, therefore DP5 is not deforming horizontally

For point DP6 (e_n= 4.3826mm)

$D_v = \sqrt{(1^2 + 1^2)} = 1.414mm$

Since $D_v < e_n$ (1.414mm. < 4.3826mm)

Then the horizontal deformation does not exceed the expected error bound, therefore DP6 is not deforming horizontally

For point DP7 (e_n= 4.3826mm)

$D_v = \sqrt{(3^2 + 2^2)} = 3.605mm$

Since $D_v < e_n$ (3.605mm. < 4.3826mm)

Then the horizontal deformation does not exceed the expected error bound, therefore DP7 is not deforming horizontally.

The horizontal component does not exceed the survey error bound in all seven points and it can be concluded in this sense that the structure does not deform horizontally but only vertically. Further studies may be conducted to observe the deformation pattern.

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CHAPTER FIVE

CONCLUSION AND RECCOMENDATION.

5.1 Conclusion

In this study, four reference stations and three monitoring points were used. The structural integrity of the tide gauge concrete structure was monitored using automatic level and tachometry observation, with the orthometric height of the reference stations being determined with respect to a nearby benchmark NAVI and that of the monitoring points being determined at two epochs of two years' interval with respect to the reference stations using automatic level and total station.

With the aid of the MATLAB software, the observations/heights were adjusted using the parametric model method of the least square adjustment technique, and the accuracy of the adjusted height was assessed by performing statistical analyses like the evaluation of posterior variance and height confidence intervals.

The computed difference in height were used to evaluate the magnitude of displacement of each of the monitoring points between the first and the subsequent epoch observations, and the displacement confidence interval of each of the monitoring points was also computed at 95% confidence interval and compared with the adjusted two epoch observations of each of the monitoring points.

Based on the data analysis of this study, it has been determined that the structure is deforming vertically rather than horizontally. This conclusion is based on the following findings and observations:

Measurement data: The collected data consistently indicate vertical displacement of the concrete structure. The measurements consistently show changes in the vertical position of the structure over time, while horizontal displacement remains relatively stable.

5.2. Recommendations

Based on results analysis and conclusion, I recommend that;

I. Further investigation and monitoring should focus on understanding the causes and mechanisms behind the vertical deformation of the concrete structure. This may involve

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additional monitoring techniques such as inclinometers or tilt meters specifically designed to measure vertical displacements.

II. Furthermore, it is crucial to assess the potential implications of vertical deformation on the structural integrity and long-term stability of the concrete structure. This evaluation should be carried out by qualified in order to determine if any remedial actions or strengthening measures are required.

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APPENDIX

Levelling data

DEFORMATION MONITORING OF TANGA TIDE GAUGE

LEVELLING BOOKING SHEET

BOOKER : NGUMU PIUS
OBSERVER : NGUMU
WEATHER : RAINY.

INSTRUMENT ; SOKKIA LEVEL
LOCATION : TANGA

RAISE AND FALL LEVELLING SHEET.

SHEET NO.

STATION	BS	IS	FS	R	F	RL	D	REMARKS
Bm 02	1.625					5.123		
P1	1.461		1.523		-0.273	4.85		
P2	1.295		1.48	0.031		4.331		
P3	1.639		1.48		0.135	4.746		
P4	1.66		1.325	0.314		5.06		
PCD	1.067		1.183	0.477		5.537		
DP6		2.084			1.017	4.52		
DP1		2.081		0.002		4.523		
DP?		2.087			0.006	4.517		
DP3		2.021		0.006		4.523		
DP2		2.028			0.007	4.516		
DP?		2.099	0		0.011	4.505		
P?	1.637		1.499	0.6		5.105		
PCD	1.07		1.204	0.433		5.538		
PP1		2.025			1.015	4.523		
PP6		2.032			0.008	4.52		
DP7		2.091			0.008	4.517		
DP5		2.036		0.005		4.522		
DP?		2.092			0.006	4.516		
PCD		2.103			0.011	4.505		
P6	1.237		1.07	1.033		5.538		
P7	1.281		1.551		0.314	5.224		
P?	1.409		1.607		0.323	4.901		
P?	1.339		1.284	0.125		5.026		
Bm 02	1.531		1.3	0.039		5.066		
			1.472	0.059		5.124		
SUMMATION								

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DEFORMATION MONITORING OF TANGA TIDE GAUGE

LEVELLING BOOKING SHEET

BOOKER: NGUNO DEUC
WEATHER: RAINY
OBSERVER: NGUNO DEUC

INSTRUMENT: SOKKIA
LOCATION: TANGA

RAISE AND FALL LEVELLING SHEET. SHEET NO ________.

STATION	BS	IS	FS	R	F	RL	D	REMARKS
PCD	1.178					5.537		
DP1		2.192			-1.014	4.523		
DP6		2.195			0.003	4.52		
DP7		2.198			0.003	4.517		
DP4		2.21			0.012	4.505		
DP2		2.199		0.011		4.516		
DP5		2.192		0.007		4.523		
P1	1.14		1.203	0.989		5.512		
P2	1.295		1.664		0.524	4.988		
P3	1.936		1.706	[illegible]	0.411	4.577		
P4	1.431		1.406	0.153	[illegible]	5.107		
Bm01	1.506		1.448	0.033	[illegible]	5.14		
NAV1			1.493	0.015	[illegible]	5.15		
SUMMATION								

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DEFORMATION MONITORING OF TANGA TIDE GAUGE

LEVELLING BOOKING SHEET

OBSERVER . MATHIAS PETER
BOOKER . NGUMO DEUS
WEATHER · RAINY

DATE: 22TH APR 23
INSTRUMENT SOKKIA
LOCATION: TANGA

RAISE AND FALL LEVELLING SHEET.

SHEET NO.

STATION	BS	IS	FS	R	F	RL	D	REMARKS
BM01	1.29							
P1	1.327		1.432		0.142			
P2	1.285		1.363	0.026				
P3	1.582		1.37		0.135			
P4	1.61		1.255	0.327				
PCD	1		1.29	0.32				
DP6		2.016			1.016			
DP1		2.013		0.003				
DP7		2.019			0.006			
DP5		2.013		0.006				
DP2		2.02			0.007			
DP4		2.031			0.011			
P5	1.578		1.61	0.421				
PCD	0.995		0.967	0.611				
DP1		2.012			1.014			
DP6		2.015			0.003			
DP7		2.018			0.003			
DP5		2.013		0.005				
DP2		2.021			0.008			
DP4		2.03			0.009			
PCD	1.324		0.998	1.022				
P6	1.292		1.653		0.329			
P7	1.267		1.616		0.324			
P8	1.297		1.226	0.141				
P9	1.471		1.239	0.058				
BM01			1.413	0.058				
SUMMATION								