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ASSESMENT AND MONITORING HORIZONTAL DEFORMATION OF MFUGALE FLYOVER

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ASSESMENT AND MONITORING HORIZONTAL DEFORMATION OF MFUGALE FLYOVER

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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

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **"Assesment and monitoring horizontal deformation of Mfugale flyover"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

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(Main Supervisor)	(Second Supervisor)
Date ………………………	Date ………………………

DECLARATION AND COPYRIGHT

I, JUMANNE MASEMBO hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

…………………………………..

MASEMBO JUMANNE

22797/T.2019

(Candidate)

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I would like to begin by expressing my outmost gratitude to the Lord, the Almighty, for guiding and supporting me throughout my journey and for bringing me this far. I firmly believe that his presence and guidance have been instrumental in my achievements, and I trust that he will continue to be by my side in all future endeavors.

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DEDICATION

This research is wholeheartedly dedicated to my beloved parents, who have been a source of inspiration and gave me strength who continually provide their moral, spiritual, emotional and financial support. To my sister, brothers, relatives, mentor, friends who shared their words of advice and encouragement to finish this study in time.

Lastly, I dedicated this book to The Almighty God, thank you for guidance, strength, power of mind and skills as well as healthy life to complete this task.

ABSTRACT

Deformation monitoring is vital as it helps to ensure structure safety, when structure is subjected to external forces, which might weaken the structure. Some of external forces causing deformation includes tides ocean loading (effects due to elastic response of earth's crust), plate tectonics, compressible and collapsible soils, swelling and shrinking of the clay soil, land slide and anthropogenic factor that contribute to land. Deformation can be detected using geodetic and non-geodetic techniques.

Tanzania under Tanzania National Roads Agency (TANROADS) constructed Mfugale flyover at Tazara road junction in 2016. The traffic loading when the vehicles move up and down the bridge and overloading of heavy trucks moving through the bridge, may cause deformation and the results may endanger people's lives who use that bridge.

This study sets to monitor deformation of Mfugale flyover and also estimating the rate at which the bridge is deforming annually. Since its construction in 2016, two epochs have been conducted. This study uses third epoch of observation for investigating both horizontal deformation. In this study, Geodetic techniques were employed and the main instrument used was Leica TS09 Total station. The bridge had eight object points (TR1, TR2, TR3, TR4, TR5, TR6, TR7, and TR8) installed on the columns of the bridge and were re-observed by tacheometry observation and 2D coordinates were obtained which serves as the third epoch by basing on the control points TZR1, TZR2, TZR3 and TZR4 that were previously established by GPS observation.

The analysis was done by computing displacement between the two epochs and compared the displacement with the theoretical statistical values using standard test at 95% confidence interval. The object points TR3 and TR5 were found to be undergoing displacement at the rate of 2.8mm/year and 2.9mm/year. However, these results do not show clearly if the structure is undergoing deformation due to different reasons. Among the reason is the existing geodetic network as it does not allow one to have multiple observations on a single object point. Moreover, instrument used may not be sufficient to quantify the results hence more precise instrument such as extensometer should be used along geodetic measuring instruments and also the methodologies used were not suitable for monitoring vertical deformation and this is because the objects points were installed on the column of the bridge in such a way that it was not possible to run level through those points and monitor vertical deformation of the flyover thus horizontal deformation only was assessed.

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ACRONYMS AND ABBREVIATIONS

3D	Three dimensions
GPS	Global Positioning System
EDM	Electronic Distance Measurement
GNSS	Global Navigation Satellite System
VLBI	Very Long Baseline Interferometry
TANROAD	Tanzania National Roads Agency

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Deformation monitoring refers to the systematic measurement and tracking of the alteration in the shape or dimensions of an object as a result of stresses induced by applied loads. (Razak, 2008). Deformation can also be defined as changes a body undergoes in its dimensions, shape and position. Such displacements are significant when they are sufficient to cause damage to buildings, structures or infrastructures. Natural factors causing deformation includes tectonic phenomena, earthquake, landslides, groundwater level changes and tidal phenomena while artificial factors include human activities such as mining, quarrying and engineering excavation (Issaka, 2020). There are different kind of structures that have been constructed such as dams, bridges and locks that do need periodic surveys to monitor movement and settlements of these structures. Any indication of abnormal behavior of this structure may threaten the safety of that structure. Monitoring of the loads on a structure and its response to them can assist determining abnormal behavior of that structure (Kalkan, 2014).The demand for structural health monitoring system for bridges has grown over the years. Structural deformation monitoring is more often used to refer to methods which access the health status of the structure and make estimation of its remaining lifetime. However, structures can be kept in service if they do not risk the safety of the user (Hunkungwe, 2013). Bridges are one of the important infrastructures to the national economy, which are considered as crucial links in transport network. Monitoring bridge deformation is the vital task in bridge maintenance and management.

This research was conducted at Mfugale Flyover which is found in Dar-es salaam connecting the Nyerere road and the Nelson Mandela Road found at Tazara road junction. Mfugale flyover is a modern infrastructure project aimed at reducing traffic congestion and improving mobility in the city and its construction started in 2016 and completed in late 2018 (Abasi, 2021). It has the length of about 200m, width of about 7m for one lane and it has two lane carriageways in North-side and South-side. The flyover was constructed as part of the Dar es salaam Strategic Transport Master plan, which seeks to provide efficient and sustainable transport solutions to meet the growing demands of the city's population. The flyover allows vehicles in one road to pass over the intersection directly, thus reducing congestion.

The transit time of public buses connecting peripheral areas to the city center has also been significantly reduced. Also, the residents who use the flyover are now spending their time more productively instead of waiting in traffic jams. Due to this merit to the economy this structure is greatly in need to be monitored to protect the national investment. Figure 1.1 shows the Mfugale Flyover.

Figure 1.1: Mfugale flyover

Source: (constructionreviewonline.com/2018/09/tanzanias-president-to induct-us-45m-tazara-flyover/)

Two previous studies analyzed deformation of Mfugale Flyover, the one by Mohere (2019) and the other by Abasi (2021). They carried out levelling and tacheometry observations to collect data and produced epochs which were used to determine if there are changes in position of the bridge by comparing them. The study by Mohere produced the first epoch which included 8 object points but it was not enough to compute displacement therefore he decided to simulate the data so as to be able to examine deformation of the bridge and later on concluded that the bridge is deforming at 3 to 5mm/year. The study by Abasi produced the second epoch which also concluded some points to be deforming and some were not deforming at rates of 2 to 5mm/ year. However, first and second epoch did not show clear results due to some limitations such as short period of time between the first and second observation.

There are many bridges that collapsed in various places in the world and resulted into negative impacts. For example, the Quebec Bridge in Canada collapsed on September 11, 1916 due to a design flaw of the actual weight of the bridge was heavier than it carrying capacity, which caused it to collapse twice, first in 1907 and second time in 1916 resulting into 95 deaths from both tragedies (Pearson & Delatte, 2006). Figure 1.2 show the Quebec bridge in Canada after it collapsed.

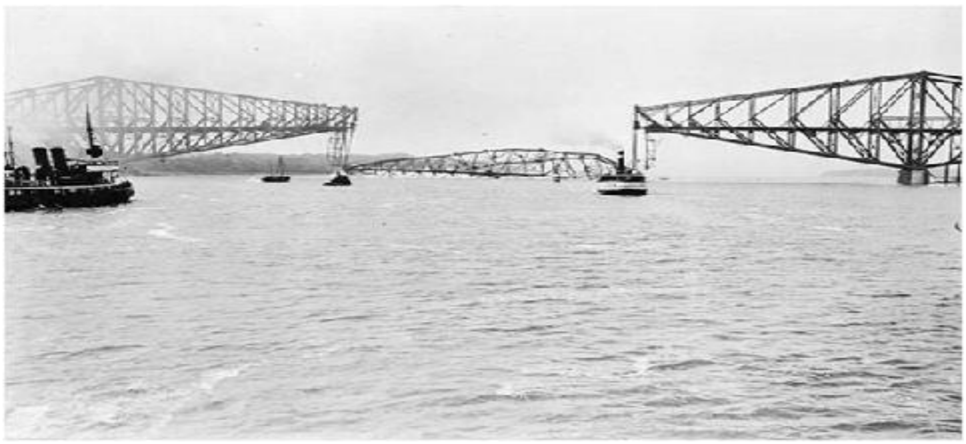

Figure 1.2: Quebec Bridge, Canada

Source: (https://commons.m.wikimedia.org) (September, 2009)

On October 21, 1994 the Seongsu Bridge in South Korea collapsed. The structural failure was caused by improper welding of the steel trusses of the suspension structure beneath the concrete slab roadway being among internal properties of the structure. In this case about 32 people died and about 17 people were injured (Kim, 1997). Figure 1.3 shows the Seongsu bridge after it collapsed.

Figure 1.3: Seongsu Bridge, South Korea

Source: (https://commons.m.wikimedia.org) (October, 1994)

On July 17, 1918 the Hyatt Regency Skywalks, Kansas City two suspended walkways were crowded with some people who were dancing. Architects theorized after the collapse that vibrations by the dancers might have contributed to the structural breakdown, as did the sheer weight of the crowd, there were 114 deaths (Turner, J.A & Johnson , D.R., 1985). Figure 1.4 shows the Hyatt Skywalks in Kansas City after it collapsed.

Figure 1.4: Hyatt Regency Skywalks, Kansas City

Source: (https://structurescentre.com) (June, 2020)

There has been different contributor of bridge collapse in Tanzania and the main contributors being tidal phenomena, tectonic phenomena, earthquake, changes of ground water level, landslides, compressible and collapsible soils, swelling and shrinkage of clay soils and other factors being flooding and heavy trucks. For example, in Dar es Salaam along the Bagamoyo road the bridge joining Mbezi and Makonde area collapsed due to heavy rainfall on 26th October, 2017. This resulted into massive destruction of properties in the area although they were no people who died or injured in the incident (Mwalongo, 2012) as shown in Figure 1.5 below.

Figure 1.5: Bridge at Mbezi Makonde in Dar es Salaam

Source: (https://www.google/latestnewstz,blogspot.com)

On Sunday 21st April, 2002 in Tanzania a bridge collapsed cutting one of the main routes inland from the Dar es Salaam. It occurred when a truck crushed through the wall of the bridge. Police stated that the bridge had already been weakened by swollen river running beneath it. At least three people were killed in the crash; hundreds of others travelling were left stranded. This incident took place at Mkwazi, 130km West of Dar es salaam (Abasi, 2021).

All these unfortunate events happened as the result of not monitoring these structures. Failure to monitor these structures, it becomes difficult to determine their life expectancy and thus results into their collapse.

The two studies by Mohere (2019) and Abasi (2021) are not sufficient to quantify if the bridge is deforming or not. Hence, this study as the third epoch is conducted to monitor and assess vertical and horizontal deformation of Mfugale Flyover so as to ensure safety of the people and avoid accidents that may occur as the result of the collapse of the bridge.

1.2 Problem Statement.

Mfugale flyover is one of the long, wide and tall engineering structures in Tanzania that needs to be monitored to ensure its structural stability after its construction, however since its construction it has been observed twice and a monitoring scheme has been established. Previous studies have observed two epochs of deformation assessment for the Mfugale Flyover, conducted in 2019 and 2021. However, the first epoch relied on simulation and the second epoch still gave unclear results since the results were inconsistent. It was estimated that the bridge would deform at a rate 0f 3-5 mm per year while the second epoch indicated a deformation rate of 2-5 mm per year. Yet, both epochs lacked the level of details required to accurately assess the rate of deformation. Therefore, in order to address the limitations and gain a more comprehensive understanding of the deformation behavior of the Mfugale bridge, this study aims to conduct a third epoch of deformation assessment. By comparing the new observations with the previous ones, this research aims to determine whether the bridge is deforming and, if so, to ascertain the rate at which is deforming to ensure the long-term structural integrity and functionality of the Mfugale Flyover as well as the security of the people using it.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of the research is to monitor horizontal deformation of Mfugale Flyover.

1.3.2 Specific Objectives

i. To determine the rate of horizontal positional deformation using tacheometric observation

ii. To perform statistical analysis for the rates to assess the rates of deformation of the bridge.

1.4 Scope and Limitations

This study mainly concentrates on determination of the horizontal displacements for the points on the column of the Mfugale Flyover, analyzing the displacements to see whether they have significant effect on the bridge or not. The sources of data in this study are expected to be secondary and primary data where secondary data is obtained from previous researches while primary data through field observations.

1.5 Beneficiaries

The beneficiaries of this research include Ardhi University and Tanzania National Roads Agency (TANROAD) since they are the primary stakeholders of the Mfugale Flyover and also, people who use the bridge to move from one place to another.

1.6 Significance of the Research

This study will help in ensuring safety of the Mfugale Flyover and the people as its conducted to inspect whether or not, movement in the bridge is taking place and also whether the bridge is stable and safe or not.

1.7 Expected outcome

The expected outcome of the research is to detect any changes or abnormalities in the bridge. This could include changes in the alignment of the bridge. The data collected from monitoring can be used to identify potential safety hazards and to plan for necessary repairs and maintenance. The outcome also includes identifying the causes of deformation, whether it is due to natural or human-induced causes.

CHAPTER TWO

LITERATURE REVIEW

This chapter is crucial as it presents a thorough evaluation of prior research and studies conducted on bridge monitoring system. The chapter explores the theories and some principles that form basis of the topic, as well as the various methods used for monitoring bridge deformation. It serves as a basis for the research and helps to establish the study's importance.

2.1 Deformation Analysis

Deformation analysis is conducted purposely for the detection, localization and modelling of geometrical change of shape, size and position of the structure, such an analysis provides valuable information about the deformation of physical and man-made objects on the earth surface. In the deformation studies, changes are detected from repeated measurements. The observations of each epoch are adjusted independently. From coordinate differences between the epochs, the parameters of the deformation model are estimated and conclusions on the object deformations are drawn. Any object, undergoes changes in space and time. Deformation refers to the changes a body undergoes in its shape, dimension and position. Since the results of deformation surveys are directly relevant to the safety of human life and engineering surveying, recently deformation analysis has become more important (Kaplan & Tevfik, 2004). During deformation studies, the used measurement techniques and systems, which could be geodetic or non-geodetic, are determined considering the type of the structure of which deformations will be monitored, its environmental conditions and expected accuracy from the measurements. As related the used monitoring techniques, the deformation measurements equipment's are varied. Also, according to professions who use the deformation monitoring techniques, these techniques and instrumentation have traditionally been categorized into two groups.

Geodetic surveys, which include conventional (terrestrial such as height differences, angle and distance measurement) and this method requires line of sight but also the accuracy of this method depends on distance to the measured points and metrological condition, photogrammetric (terrestrial, aerial and digital photogrammetry) this involves the use of high resolution and coordinated metric cameras, space systems (such as Global Positioning System-GPS, VLBI, InSAR).

2.2 Deformation Monitoring Techniques

Historically, many different methods have been used to monitor the deformation of large structures. New monitoring techniques and methodologies emerge as new technology is developed and enhanced, for example, the combination of a total station with image-based measurement systems or laser scanners. Each monitoring scheme has unique advantages, disadvantages and limitations whether it is based on traditional geodetic surveying techniques, geotechnical measurements, the global positioning system (GPS), or remote sensing principles. The cost effectiveness and reliability of a monitoring scheme are important factors on the decision to implement a certain monitoring system over another (Gairns, 2008).

2.2.1 Non-Geodetic Methods

In non-geodetic methods, geotechnical and specialized monitoring devices are used to study deformation of engineering structures. They are required only if greater accuracy is sought or if measuring points are inaccessible to geodetic methods. However, in general whenever non-geodetic instruments are used to monitor deformation, geodetic methods are also used to relate measurements to a reference datum (Shan-Long, 1991). Non-geodetic techniques have mainly been used for relative deformation measurements within the deformable object and its surrounding.

2.2.2 Geodetic Methods

This method includes terrestrial geodetic methods, photogrammetric methods and space techniques and are used to monitor the magnitude and rate of horizontal and vertical deformation of structures, the ground surface, and accessible parts of subsurface instruments in a wide variety of construction situations. Geodetic techniques, through a network of points interconnected by angle and/or distance measurements, usually supply a sufficient redundancy of observations for the statistical evaluation of their quality and for a detection of errors. They give global information on the behavior of the deformable structure. Geodetic techniques have traditionally been used mainly for determining the absolute displacement of selected points on the surface of the object with respect to some reference points that are assumed to be stable (Erol S & Ayan T, 2008). This study employed geodetic techniques in monitoring deformations of the bridge. Geodetic techniques are categorized into;

- Remote sensing or satellite techniques with space-derived information have significant potential for landslide hazard assessment and for improved understanding of landslide processes. Similar sensors and methods are of importance for seismic hazards and management of earthquake disasters.
- Photogrammetric techniques can be an effective tool for monitoring actively moving landslides and for analyzing the velocity or strain-rate fields. These techniques allow the determination of ground displacements over long periods of time, by comparing the corresponding sets of aerial photographs.
- Ground-based geodetic techniques make use of many instruments and methods of measurement for absolute displacement computation. They are usually employed according to an episodic monitoring program. In some cases, the geodetic sensors are put on control points and perform the measurements during each repetition. In other cases, a sensor can permanently be put on an observation point and perform measurements to targets on control points according to a computer-controlled program.
- Satellite-based geodetic techniques make use of satellite positioning systems, such as the Global Positioning System, GPS. There are a number of methodologies applied that can guarantee high accuracy, continuous and reliable results (Savvaidis, 2003)

2.3 Types of Control Points for Deformation

Deformation monitoring involves the measurement and analysis of changes in position or shape of structures. To establish a reliable reference frame for such studies, control points are used as fixed reference markers. The following are types control points for deformation;

2.3.1 Object Control Points

These are control points established on the deformable body and this is possible when deformable body can be isolated from the stable part.

2.3.2 Reference Control Points

These are control points established outside the deformable body on the area which is considered to be stable.

2.4 Deformation Monitoring Networks

Most deformation monitoring schemes consist of measurements made to the monitored object that are referred to several reference points so that two basic types of geodetic network are distinguished

2.4.1 Absolute Monitoring Network

This is a monitoring network in which some control points are installed inside the deformable body or object and others are reference installed outside the deformable body as shown in Figure 2.1. The general procedure to monitor deformation of structures and its foundation involves measuring of the spatial displacement of the selected object points (i.e monitoring points) from external reference points that are fixed in positions. Both terrestrial and satellite method are used to measure these geospatial displacements. Subsequent periodic observations are then made relative to these reference points (US Army Corps of Engineers, 2018)

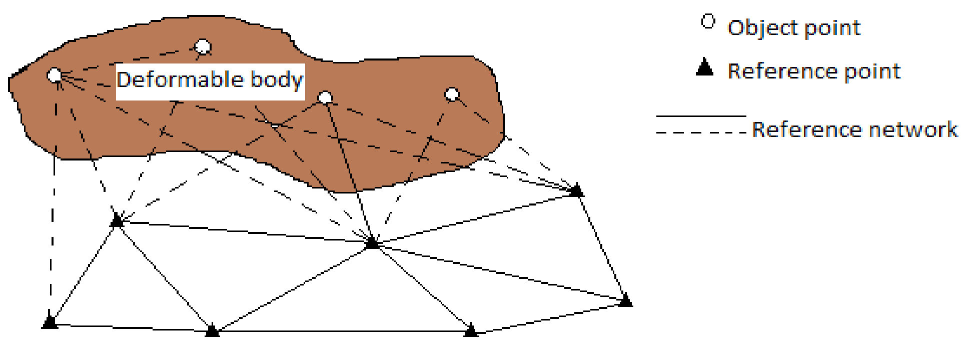

Figure 2.1: Absolute Monitoring Network

Source: (https://prezi.com/../absolute-deformation-monitoring-network)

2.4.2 Relative Monitoring Networks

In relative networks, all the survey points are assumed to be located on the deformable body, the purpose in this case is to identify the deformation model, i.e., to distinguish, on the basis of repeated geodetic observations, between the deformations caused by the extension and shearing strains, by the relative rigid body displacements, and by the single point displacements. When the reference points are located in the structure, only relative deformation is determined, method used is to freeze the mean deformation for instance, micrometer joint measurements are relative observation (US Army Corps of Engineers, 2018). Figure 2.2 below shows the relative monitoring network.

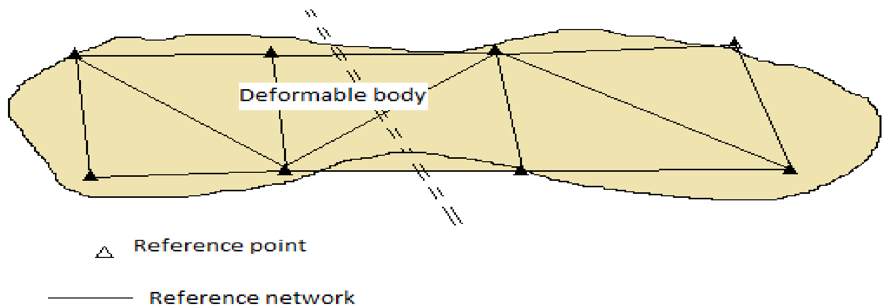

Figure 2.2: Relative monitoring network

Source: (https:/prezi.com/../ relative-deformation-monitoring-network)

This study used geodetic methods specifically the ground-based geodetic techniques since the measuring points were accessible to these techniques and also it is easier to have absolute displacement computation.

2.5 Related Studies on Deformation Monitoring

Silas (2018) conducted a study on deformation monitoring of Tanga Tide gauge using GPS, level and total station. The need for establishment of Geodetic control network for Tanga tide gauge platform in deformation monitoring was addressed in this research based on determination of 3D structural movement by referring a network of control points outside the structure. The main objective of this research was to establish three-dimension geodetic network for assessing both vertical and horizontal movement of the gauge. Three observation process were carried out that is GPS observation, levelling and tacheometry to give out position on the monumented points (Silas, 2018). Three points were installed on the tide gauge platform where at the end of the study, two points were found to be stable while one was not.

Mashauri (2021) conducted a study concerning the monitoring structural deformation of Machinga Complex Overhead Bridge at Ilala Municipal in Dar es Salaam city. Since its construction in 2008 only two epochs in vertical deformation have been observed. The first epoch was conducted in 2012 followed by the second epoch in 2015 and then the third in 2017. This research describes the observation for third epoch for vertical 1D and planimetric 2D to make 3D monitoring network. In this research three geodetic observation processes (GPS observation, levelling and tacheometry) were performed to give position on the monumented points. The researcher concluded that the objects point BP1 and BP2 on the bridge were deforming at 0.35mm/year and 0.9mm/year respectively and recommended that more studies should be done (Mashauri, 2021).

Mobil (2018) conducted research on Network Design and Deformation Monitoring of Ruvu Bridge. This research described observation for first epoch for vertical 1D and planimetric 2D to make 3D monitoring network. There was also the second epoch that was performed for vertical observation; it was performed to assess short time displacement for vertical component from 1D data in first epoch. The researcher performed precise levelling at benchmark BM01 and ended at the same benchmark. GNSS technique was used to obtain 2D coordinates. In the end the researcher concluded that all object points were stable and recommended more observation (Mobil, 2018).

Takana and Umar (2017) established geodetic control networks for monitoring Jimeta Bridge in Nigeria. In this research GPS was used to carry out observation on remote stable monuments serving as the control network and arrays of selected monitoring points on the bridge to serve as monitoring points. These stations form a triangulation network, where the baselines between the monitoring points are formulated to monitor differential movement. The researcher used four control points for deformation monitoring of Jimeta Bridge (Takana & Umar, 2017). They managed to establish the network and the data obtained were subjected to statistical test to ascertain its goodness of fit and network connectivity variance of the unit. The test indicates that there are no blunders detected in data.

This study also is concerned with deformation monitoring of Mfugale Flyover found at Ilala Municipal in Dar es salaam connecting the Nyerere and Mandela Road. The main objective of this study was to monitor vertical and horizontal deformation of Mfugale Flyover. Geodetic techniques were employed to carry out the task by performing tacheometric observations so as to obtain the 3D coordinates of the object points that were found on the columns of the bridge that were later compared with those existing coordinates previous studies.

CHAPTER THREE

METHODOLOGY

This chapter deals with deformation monitoring using observation as well as monitoring using planimetric data. The process commenced with site visit to understand the location of existing survey controls that have been used. The process then proceeds with data collection and processing procedures.

3.1 Reconnaissance

This is the most important aspect of any survey, which must be undertaken before field work commences. It involved both office and field reconnaissance. In the case of office reconnaissance, data from previous study for deformation of Mfugale Flyover were obtained from previous studies. Adjusted coordinates were obtained which includes 2D positions of the monitoring points TZR1, TZR2, TZR3 and TZR4 as the reference points located away from the bridge and the object points TR1, TR2, TR3, TR4, TR5, TR6, TR7 and TR8 located on the columns of the bridge.

For the case of site reconnaissance, the study examined the existing control points if they are still in-situ and that they can still be used for the study intended. Furthermore, the site reconnaissance examined the nature of the site and help to plan and schedule field activities at the Mfugale Bridge. Figure 3.1 below shows one of the object points installed on the column of the bridge.

Figure 3.1: Object point installed on the column of the bridge

3.2 Field observation on the existing network

This study applied absolute network at Mfugale bridge due to its scale and capability of identifying the object points and reference points. The observation was based on the network which was designed from the previous study such that one reference point is inter-visible to at least four object points. This network consists of four reference station and eight object points as shown in Figure 3.2 below.

Figure 3.2: Existing micro-geodetic network at Mfugale Bridge

3.3 Instrumentation

In this study the instruments used include Leica total station TS09 (Figure 3.3), steel tape, tripod stands, reflectors and kin pole stands. The main instrument used was the total station It is an instrument that combines the angle measurements that could be obtained with a traditional theodolite with electronic distance measurement. Taping distance, with all its associated problems, has been rendered for all baseline measurement. Distance can now be measured easily, quickly and with greater accuracy, regardless of terrain conditions.

Figure 3.3: Leica Total Station TS 09

Tracking modes, for setting out of distance, repeat the measurement several times a second. Total stations with their inbuilt EDM enable; Traversing over great distances, with much greater control of swing errors; the inclusion of many more measured distances into control networks, rendering classical triangulation obsolete. This results in much greater control of scale error. Also setting-out and photogrammetric control, over large areas, by polar coordinates from a single baseline. Further, it enables deformation monitoring to sub-millimetre accuracies using high-precision EDM, such as the Mekometer ME5000 (Schofield & Breach, 2007).

3.4 Pre analysis

Pre analysis is the analysis of the component measurements of a survey project before is undertaken. Pre analysis is of great importance due to the following reasons helps overall design of the project, meet the required specification (tolerance), selection of suitable measurement, to plan measurements procedure and to provide basics for evaluation of accuracy of survey measurement. In this study the main instrument used was the Leica Total Station TS09. The instrument was examined in order to understand the maximum tolerance that can be expected when using it in deformation analysis.

3.4.1 Leica total station (TS09)

From the instrument specification,

$\sigma_\alpha = 3''$ and σ_d = 2mm + 2ppm

From

$\sigma_d = \sqrt{\sigma\alpha^2 + \sigma d^2}$

$\sigma_d = 2\text{mm} + \frac{2\text{x}50}{1000000}$

σ_d = 2mm + 0.0001

$\sigma_\alpha = \frac{3\text{x}\Pi}{3600\text{x}18}$

σ_α = 0.0000145444

$\sigma = \sqrt{(2 + 0.0001)^2 + 0.0000145444^2}$

σ = 2mm

Therefore, the expected standard deviation in determining 3D position using total station TS09, is 2mm.

Also, the instrument's error was checked and the following were the procedures that were involved.

- ❖ The Leica total station (TS09) was set up at point A.
- ❖ The target was also set at point B a distance of 10m that was measured with a tape from the Leica total station (TS09),
- ❖ A series of 10 measurements at the same point using the Leica Total Station (TS09) were taken.
- ❖ The measured distances for each measurement were recorded as shown in the Table 3.1

Table 3.1: Distance measured by Leica Total Station (TS09)

S/N	**Distance (m)**
1	19.95
2	20.002
3	20.001
4	20.000
5	19.998
6	19.997
7	20.003
8	20.000
9	19.999
10	20.002

- ❖ Then mean was calculated from these measurements and this resulted into a mean of **19.9995m.**
- ❖ Then deviation from mean for each measurement was computed from Deviation from mean = Measurement – Mean and they are squared. The results were presented in the Table 3.2

Table 3.2: Deviation from mean and square of deviation

S/N	**Distance (m)**	**Deviation from mean (m)**	**Square of deviation (m^2)**
1	19.95	-0.0045	0.00002025
2	20.002	0.0025	0.00000625
3	20.001	0.0015	0.00000225
4	20.000	0.0005	0.00000025
5	19.998	-0.0015	0.00000225
6	19.997	-0.0025	0.00000625
7	20.003	0.0035	0.00001225
8	20.000	0.0005	0.00000025
9	19.999	-0.0005	0.00000025
10	20.002	0.0025	0.00000625

- Then the sample variance was calculated from, Sample variance = sum of squared / (No. of measurements - 1) and it resulted into **0.0000073611m²**.
- From there standard deviation was calculated

  From, Standard deviation = $\sqrt{\text{Sample } Variance}$

$$\sqrt{0.0000073611\text{m2}}$$

$$= 0.0027127\text{m}$$

Therefore, the measurements obtained from the Leica Total Station (TS09) was **2.7127mm/20m**

3.5 Datum Check

Before the design and execution of survey, the study decided to examine the existing control points if they are in-situ and if the precision of their establishment meet the intended purpose. Doing this study conducted datum check on the points TZR1, TZR2, TZR3 and TZR4. Table 3.3 and Table 3.4 shows datum check.

Table 3.3: Datum check for points TZR2 and TZR3

Station	**N**	**E**		°	'	"	
TZR2	9243485.56	527232.407	Brg	354	50	52	
TZR3	9243558.379	527225.814	S(c)	73.114		MS	
	72.819	-6.566	S(m)	73.117		diff	0.003

Comparing computed and measured to find out if they differ to an acceptable limit.

$\frac{Sm-Sc}{Sc} \leq$ 1:10,000

$\frac{0.003}{73.114}$ = 1:24,371

Therefore, it is within the acceptable limit as 1:24,400 ≤ 1:10,000

Table 3.4: Datum check for points TZR1 and TZR4

Station	**N**	**E**		°	'	"	
TZR1	9243427.771	527122.327	Brg	290	51	37	
TZR4	9243462.168	527032.062	S(c)	96.597		MS	
	34.397	-90.265	S(m)	96.599		diff	0.002

Comparing computed and measured o find out if they differ to an acceptable limit.

$\frac{Sm-Sc}{Sc} \leq$ 1:10,000

$\frac{0.002}{96.597}$ = 1:48,300

Therefore, it is within the acceptable limit as 1:48,300 ≤ 1:10,000

By considering the results above, the study confirms that the reference points are in-situ and therefore tacheometry observation can take place to coordinate the object points on the bridge.

3.6 Tacheometry observation

During reconnaissance, the coordinates of the reference points as well as the object points were obtained from the previous study. This study re-observed these object points TR1, TR2, TR3, TR4, TR5, TR6, TR7 and TR8 while basing on the reference points TZR1, TZR2, TZR3 and TZR4. Table 3.5 shows the third epoch tacheometry data for measured object points.

Table 3.5: Third epoch tacheometry data for measured object points

POINT ID	EASTING	NORTHING
TR1	527246.620	9243515.511
TR2	527207.534	9243497.325
TR3	527242.115	9243536.887
TR4	527198.750	9243516.357
TR5	527096.430	9243470.883
TR6	527137.528	9243489.543
TR7	527106.972	9243450.643
TR8	527147.022	9243427.257

3.6.1 Data observation procedures

- Initially a total station is set at TZR2 oriented to TZR3 and performed a datum check, then two points on the bridge which are TR1 and TR2 were coordinated.
- Then the total station was again set at TZR3 oriented to TZR2 and performed a datum check, then two points on the bridge which are TR3 and TR4 were also coordinated.
- Also, the total station was set at TZR4 oriented TZR1 and datum check was performed, then two points on the bridge which are TR4 and TR6 were also coordinated.
- Lastly the total station was set at TZR1 oriented TZR4 and performed a datum check, then two points on bridge TR7 and TR8 were coordinated.
- In all setups it was assured that all circular bubbles were well leveled both circular bubble in the target and circular bubble in the total station machine.

- All points on the bridge were designed to hold Leica prisms.

Figure 3.4: Tacheometry observation at the bridge column

CHAPTER FOUR

RESULT, ANALYSIS AND DISCUSSION

This chapter presents discussion and analysis of results obtained from tacheometric observations. The better presentation of the results the better the analysis. It involves processing, refinements of raw data and reduction to obtain final product which will be used for analysis with the previous surveys. The deformation was determined by analyzing the reference point and the structural point to determine the changes in the structure. Deformation analysis on this study is based on both horizontal and vertical analysis using the tacheometric data.

4.1 Comparison of the Results

The assessment of deformation requires at least two epochs of observation observed at specific interval in which displacement can be computed. The magnitude of displacement is given by subtracting the position of the recently epoch from that of the previous epoch.

Mathematically,

Displacement = $P_{2nd\ epoch}$ - $P_{1st\ epoch}$

Where, $P_{2nd\ epoch}$ is the position of the second epoch

$P_{1st\ epoch}$ is the position of the first epoch

Comparison of the data in 3D for measurements between two epochs (2021 and 2023) and their displacements are presented in the Table 4.1 and Table 4.2.

Table 4.1: Data in 2D coordinates in epoch 2 (2021) and epoch 3 (2023)

	2021		2023	
Station	E (m)	N (m)	E(m)	N(m)
TR1	527246.625	9243515.513	527246.620	9243515.511
TR2	527207.537	9243497.329	527207.534	9243497.325
TR3	527242.111	9243536.891	527242.115	9243536.887
TR4	527198.754	9243516.359	527198.750	9243516.357
TR5	527096.435	9243470.886	527096.430	9243470.883
TR6	527137.529	9243489.546	527137.528	9243489.543
TR7	527106.975	9243450.646	527106.972	9243450.643
TR8	527147.025	9243469.261	527147.022	9243427.257

Table 4.2: Differences of the data in second epoch (2021) and third epoch (2023)

	2021-2023	
Station	ΔE(m)	ΔN(m)
TR1	-0.005	-0.002
TR2	-0.003	-0.004
TR3	-0.004	-0.004
TR4	-0.004	-0.002
TR5	-0.005	-0.003
TR6	-0.001	-0.003
TR7	-0.003	-0.003
TR8	-0.003	-0.004

Usually, displacement at any rate mean the structure is deformed. There are many factors to be considered. The main factor is the allowable tolerance of deformation which is determined during pre-analysis stage. Comparison of the magnitude of the calculated displacement and its associated survey accuracy indicates whether the reported movement is more likely due to survey error. If the magnitude of displacement is less than its associated survey accuracy it showa that there is no deformation and vice versa.

Thus,

$d_n < e_n$

Where, dn - Magnitude of displacement

en- Maximum dimension of combined 95% confidence ellipse

To assess horizontal deformation, the magnitude of displacement is given by

$d_n = \sqrt{\Delta N^2 + \Delta E^2}$

Where, d_n is the magnitude of the horizontal displacement (for point n)

e_n = max dimension of combined 95% confidence ellipse. For point n, $e_n = (1.9599)\sqrt{\Delta\sigma^2 + \Delta\sigma^2}$ and $\Delta\sigma^2$ is the standard error in horizontal position (Caspary & Rüeger, 1987).

From pre analysis σ is 2 then,

$e_n = (1.9599)\sqrt{2^2 + 2^2}$

e_n =5.5434mm

Percentage confidence in horizontal movement is 5.5434mm.

4.2 Deformation Analysis

For point TR1

Magnitude of maximum displacement is

$$d = \sqrt{(-5)^2 + (-2)^2} = 5.385\text{mm}$$

Since $d_n < e_n$

5.385mm <5.5434mm

Rate of deformation per year = $5.385/2$ = 2.7mm/year

These results show that the horizontal displacement is not exceeding the expected survey error bound, therefore TR1 is horizontally not deforming.

For point TR2

Magnitude of maximum displacement is

$$d = \sqrt{(-3)^2 + (-4)^2} = 5\text{mm}$$

Since $d_n < e_n$

5mm < 5.5434mm

Rate of deformation per year = $5/2$ = 2.5 mm/year

These results show that the horizontal displacement is not exceeding the expected survey error bound, therefore TR2 is horizontally not deforming.

For point TR3

Magnitude of maximum displacement is

$$d = \sqrt{(-4)^2 + (-4)^2} = 5.657\text{mm}$$

Since $d_n > e_n$

5.657mm > 5.5434mm

Rate of deformation per year = $5.657/2$ = 2.8mm/year

This shows that the horizontal displacement exceeds the expected survey error bound, therefore TR3 is horizontally deforming at rate of 2.8mm/year.

For point TR4

Magnitude of maximum displacement is

$$d = \sqrt{(-4)^2 + (-2)^2} = 4.472mm$$

Since $d_n < e_n$

$$4.472mm < 5.5434mm$$

Rate of deformation per year = $4.472/2$ = 2.2mm/year

These results show that the horizontal displacement is not exceeding the expected survey error bound, therefore TR4 is horizontally not deforming.

For point TR5

Magnitude of maximum displacement is

$$d = \sqrt{(-3)^2 + (-5)^2} = 5.831mm$$

Since $d_n > e_n$

$$5.831mm > 5.5434mm$$

Rate of deformation per year = $5.831/2$ = 2.9mm/year

This shows that the horizontal displacement exceeds the expected survey error bound, therefore TR5 is horizontally deforming at rate of 2.9mm/year.

For point TR6

Magnitude of maximum displacement is

$$d = \sqrt{(-1)^2 + (-3)^2} = 3.162mm$$

Since $d_n < e_n$

3.162mm < 5.5434mm

Rate of deformation per year = $3.162/2$ = 1.6 mm/year

These results show that the horizontal displacement is not exceeding the expected survey error bound, therefore TR6 is horizontally not deforming.

For point TR7

Magnitude of maximum displacement is

$$d = \sqrt{(-3)^2 + (-3)^2} = 4.243mm$$

Since $d_n < e_n$

4.243mm < 5.5434mm

Rate of deformation per year = $4.243/2$ = 2.1 mm/year

These results show that the horizontal displacement is not exceeding the expected survey error bound, therefore TR7 is horizontally not deforming.

For point TR8

Magnitude of maximum displacement is

$$d = \sqrt{(-3)^2 + (-4)^2} = 5mm$$

Since $d_n < e_n$

5mm < 5.5434mm

Rate of deformation per year = $5/2$ = 2.5 mm/year

These results show that the horizontal displacement is not exceeding the expected survey error bound, therefore TR8 is horizontally not deforming.

Interpretation,

Null hypothesis (Ho): Point assumed to be stable

Alternative hypothesis (Ha): Point assumed to be unstable

Ho: $d_n < e_n$

Ha: $d_n > e_n$

Therefore,

$d_n < e_n$, the point is not deforming

$d_n > e_n$, the point is deforming

Comparison to the percentage confidence in horizontal movement can be achieved as shown on the Table 4.3.

Table 4.3: Comparison of the difference in horizontal magnitude and percentage confidence error

POINT ID	Displacements(mm)	Percentage error e_n (mm)	Remarks
TR1	5.3	5.5434	Ho
TR2	5.0	5.5434	Ho
TR3	5.6	5.5434	Ha
TR4	4.4	5.5434	Ho
TR5	5.8	5.5434	Ha
TR6	3.1	5.5434	Ho
TR7	4.2	5.5434	Ho
TR8	5.0	5.5434	Ho

The percentage confidence in the horizontal movement e_n was 95% confidence level. 5.5434mm is max dimension of combined 95% confidence ellipse, which can be used to asses horizontal deformation whether the movement is likely due to survey error.

From the table above the object points TR1, TR2, TR4, TR6, TR7 and TR8 were found to be stable since they did not exceed the instrument standard error while points TR3 and TR5 were found to be unstable since they exceeded the instrument standard error 5.5434.

Therefore, the rate of horizontal movement of the bridge is shown in Table 4.4

Table 4.4: Velocity for horizontal displacement of the bridge

POINT ID	Velocity (mm/year)
TR1	2.7
TR2	2.5
TR3	2.8
TR4	2.2
TR5	2.9
TR6	1.6
TR7	2.1
TR8	2.5

The rate was computed from the magnitude of obtained displacement and time by which two epochs were observed (two years).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusion and recommendation based on the findings of the dissertation research on the monitoring of deformation of Mfugale flyover. This chapter summarizes the key findings, draws conclusion based on the research outcomes, and provides recommendations for the effective management and maintenance of the flyover.

5.1 Conclusion

The main objective of this research was to monitor horizontal deformation of Mfugale Flyover using the existing previous data and the new obtained data which were obtained through geodetic techniques by tacheometry observation.

Based on the results and analysis in chapter four, it indicates that there is horizontal deformation of the bridge in the object points TR3 and TR5 as they have actual displacement of -5.6mm and -5.8mm at a rate of 2.8mm/year and 2.9mm/year respectively, which exceeds the allowable tolerance of 5.5434 of the instruments which was computed during the pre-analysis stage.

Other object points which are TR1, TR2, TR4, TR6, TR7 and TR8 which were on the columns of the bridge were found not to be deforming, due to the fact that their actual displacements did not exceed the allowable tolerance of the instrument.

However, these results do not show clearly if the structure is undergoing deformation due to different reasons. Among the reason is the existing geodetic network as it does not allow one to have multiple observations on a single object point. Moreover, instrument used may not be sufficient to quantify the results hence more precise instrument such as extensometer should be used along geodetic measuring instruments and also the methodologies used especially on monitoring vertical deformation was not suitable and this is because the objects points were installed on the column of the bridge in such a way that it is not possible to run level through those points and monitor vertical deformation.

5.2 Recommendation

For the safety and security of the Mfugale flyover, deformation monitoring has to be done more regularly since more epochs are required to assess the structural deformation. The existing geodetic network that was used to monitor Mfugale flyover has to be improved to allow redundant observations. Also, the methodology used to monitor deformation has to be changed and involve the use of other methods such as photogrammetric and remote sensing techniques. Moreover, precise instruments such as extensometer should be used along geodetic measuring instrument.

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