ARDHI UNIVERSITY

RE-ESTABLISHMENT OF HORIZONTAL NETWORK AND VERTICAL DEFORMATION MONITORING OF RUVU BRIDGE

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BSc. Geomatics

Dissertation

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RE-ESTABLISHMENT OF HORIZONTAL NETWORK AND VERTICAL DEFORMATION MONITORING OF RUVU BRIDGE

MATHIAS PETER C.

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 proof read and hereby recommend for acceptance by the Ardhi University a dissertation entitled "RE-ESTABLISHMENT OF HORIZONTAL NETWORK AND VERTICAL DEFORMATION MONITORING OF RUVU BRIDGE in fulfillment of the requirements for the Award of Bachelor of Science (B.Sc.) in Geomatics of the Ardhi University.

…………………………………

Dr. Elifuraha Saria

(Supervisor)

Date ………………………

DECLARATION AND COPYRIGHT

I Peter, Mathias declares that this research is my own original work and that to the best of my knowledge, it has not been presented to any other University for a similar or any other degree award except where due acknowledgements have been made in the text.

…………………………………..

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DEDICATION

Glory and honor is to the creator of heaven and the earth. Thanks to El Roi (Almighty God) for his protection from the beginning of this work up to the end of my research.

I dedicate this dissertation to the pursuit of knowledge and the power of curiosity. It is dedicated to the countless individuals who have dedicated their lives to expanding the boundaries of human understanding and to those who continue to do so today.

To my precious family; my father Costantine Mathias Lung'ango, my mother Debora Vicent Mizambwa and my sister Mary Costantine Mathias and my three brothers Vicent Costantine Mathias, Mathias Costantine Mathias, George Costantine Mathias and my beloved young brother Paul Costantine Mathias whose unwavering support and their prayers, and love have been the foundation of my journey. Your encouragement and belief in my abilities have fueled my determination, and for that, I am eternally grateful.

ABSTRACT

This study focuses on re_establish and analysis the network deformation monitoring of Ruvu Bridge was conducted at Kibaha municipality in Coastal Region. Since its construction on 2009, only three epochs in vertical component and two epochs in horizontal component have been observed. This work observe the fourth epoch for vertical component (1D) and re-established horizontal network through tacheometric observation and first epoch for horizontal component (2D) using Total station.

The levelling route had a distance of 338.031 meters and the misclosure was 0.000mm which was within the allowable range ±0.338031mm obtained from pre-analysis The evaluated displacement magnitudes were compared with their corresponding computed 95% confidence intervals to determine the significance of the movements. And it was found that some of the objective points RV03, RV04 and RV05 is deforming by rate 1.667mm/year,3.333 mm/year and 2.333 mm/year respectively

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ACRONYMS AND ABBREVIATIONS

BM: Benchmark

1D:	One Dimension
2D:	Two Dimension
3D:	Three Dimension
GPS:	Global Positioning System
GNSS:	Global Navigation Satellite System
EDM:	Electronic Distance Measurement
TS:	Total Station
E:	Eastings
N:	Northings

CHAPTER ONE

INTRODUCTION

1.1 Background

Deformation refers to the changes body (natural or artificial) undergoes in its shape, dimension and position. Such displacements are significant when they are sufficient to cause damage to buildings, structures or infrastructures. Many bridge failures caused by normal or abnormal loadings. Monitoring Bridge deformation is the vital task in bridge maintenance and management. The subjects of deformation monitoring include either natural objects such as ground deformation due to mining exploitation, withdrawal of oil or underground water, active tectonic plate boundaries, glacier movements etc., or the man-made objects such as dams, bridges, tunnels and other complex engineering structures (Choudhury,J.R; &Hasnat,A.(2015). Natural factors which are said to cause deformation include tectonic activities, tides, earthquakes, swelling and shrinkage of clay soil, landslides and other related factors such as groundwater variation while artificial factors (human activities) include mining, quarrying and engineering excavation (Abdullahi, 2016). The results of deformation monitoring are directly relevant to the protection of human life and environment protection. The bridges are vital subjects within the field of infrastructure management. Stability and reliability of a bridge is an indispensable in order that regular inspection and monitoring of the structure are needed. The demand for structural health monitoring systems for bridges has grown over the last few decades. In order to know the safeties of bridges, monitoring their real-time displacement and recording their fatigue history are very important. (Beshr, 2015). Bridges are one in all the important infrastructures to the economic system, which are crucial links in the transport network. Many bridge failures are caused by normal or abnormal loadings. Monitoring Bridge deformation is a vital task in bridge maintenance and management. The process of implementing a damage detection strategy for civil and mechanical engineering infrastructure is known as Health Monitoring (SHM) (Hui, 2009).

1.2 Causes and Effects of Deformed Bridges around the World

There are several situations in which bridges collapse. There are those that collapse a few days after construction and others after being in use for a long time. They may even collapse during the time of use when vehicles and people pass through leading to loss of lives and properties.

In the past century, Bridge engineers learned substantially from studying historical failures of bridges, each bridge failure has its own unique features, which makes it difficult to want a broad view of the causes of failure (Aydin,.2014). Below are a few samples of Collapsed bridges, causes and their impacts around the world.

On October 25 1994, the Seongsu Bridge in the Asian nation 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 as shown in figure 1.1 below. During this case 32 people died and 17 was injured (Pendaeli, 2017)

Figure 1.1: Seongsu Bridge in South Korea collapsed due to improper welding of steel trusses (source: https://prezi.com/.../collapse-of-the-korea-seoul-seongsu-bridge/)

On 26 May 2002, 1-40 Bridge found at Webbers falls, Oklahoma in the United States collapsed due to Barge stuck on one of the piers of the Bridge. The Bridge was a concrete Bridge for vehicle traffic over the Arkansas River. During the collapse, 14 people died as shown in figure 1.2 below.

Figure 1.2: Bridge found at Webbers falls, Oklahoma in the United States collapsed due to Barge stuck one of thepiers of the Bridge

There have been different causes of bridge collapse in Tanzania and all over the world, the main being changes of ground water levels, tidal phenomena, earthquake, tectonic phenomena, compressible and collapsible soils, swelling and shrinkage of clay soils, landslide and other contributors being heave trucks and flooding. (Choudhury & Hasnat, 2015).

On 26 October 2017 along Dar Es Salaam Bagamoyo Road, the bridge joining this route at Mbezi Makonde area collapsed due to floods caused by heavy rainfall. There were no casualties in the accident but only destruction of properties as shown in Figure 1.3.

Figure 1.3: One of the bridges at Dar es Salaam in Tanzania joining Bagamoyo road at Mbezi Makonde area after collapse.

1.3 Monitoring structural Deformation of Ruvu Bridge

Ruvu Bridge was constructed in 2009. Since then only a geodetic network was established for monitoring the deformation and the two-epoch observations were made in two months in 2018. This study intends to determine the rate of deformation, with 2 years of timespan after the first epoch, was done.

1.4 Problem Statement

The bridge has been in existence since 2009 in which both pedestrians and vehicles are using the road for different transportation uses. As an engineering structure constructed for transport uses since 2009, Ruvu Bridge usually experiences forces such as wind, traffic, temperature, tidal current as well as extreme loadings such as earthquakes and floods and typhoons. Continuous deformation monitoring of bridges has been very crucial for providing safety to people and the structure itself as well as improving design codes. Since its establishment, Ruvu Bridge has been monitored only twice in 2018 through an established geodetic network and precise leveling with two months time interval and 2020 whereby third epoch in vertical and second epoch in horizontal. Deformation monitoring usually requires at least three epochs in at least 6 months’ time interval.

This study focuses on re-establishment of horizontal network as well conducting fourth epoch precise leveling for vertical movement.

1.5 Main Objectives

The main objective of this research is to monitor both vertical and horizontal displacement of Ruvu Bridge and validate rate of change of bridge in 1D.

1.6 Specific Objectives

i. Performing GPS observation of second epoch in horizontal position
ii. Performing Leveling observations of third epoch in vertical position
iii. Assessment of horizontal and vertical displacement

1.7 Description of Study Area

Ruvu Bridge is a bridge in Tanzania Found in Coastal region in Kibaha, it was inaugurated by the Tanzanian Vice President Ali Mohamed Shein in 2009; it lies on A7 high connecting the city of Dar es salaam to other Regions. The bridge allows both pedestrians and vehicles to pass as shown in figure 1.4 and figure 1.5

The following table 1.1 shows the bridge description.

Table 1.1 Bridge description (From TANROADS)

Coordinates	6 4’26’’S 38 41’40’’,
Crosses	Ruvu bridge
Carries	A7 road (2 lanes),
Location	Coast Region Tanzania
Total length	135m
Engineering designed by	NORTHPLAN Tanzania
Constructed by	Chico (China)
Construction end	August 2008
Inaugurated	May 2009
Construction cost	TZS 44 billion
Owner	Government of Tanzania
Replaces	Ruvu Bridge

Figure 1.4: Ruvu Bridge

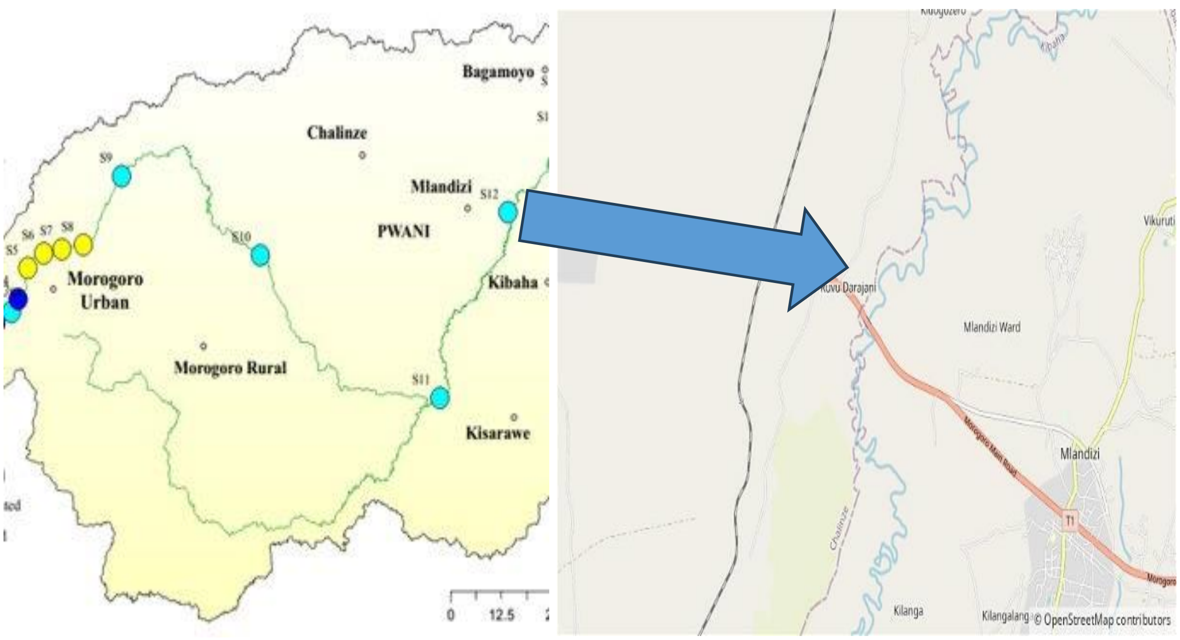


Figure 1.5: location of study area of Ruvu Bridge

1.8 Significance of the Research

This study will help in ensuring safety and security of Ruvu bridge and people who are using it, through object points that will be designed on the bridge it will be easy to detect changes or abnormal behaviors appearing on it.

1.9 Beneficiaries of the Research

i. People who are using Ruvu bridge
ii. Tanzania Roads Agency (TANROADS)
iii. Ardhi university geomatics students

1.10 Scope and Limitation

This study is mainly concentrating on calculation of both vertical and horizontal displacements for Ruvu bridge, analyzing the displacements to see whether they have significant effect on the bridge or not.

1.11 Research Structure

The study includes five major chapters. Chapter one is an introduction to deformation with its causes, impact and effort done to minimize damage that could occur due to deformation. In addition, this chapter includes various bridge failures around the world with a number Casualties involved.

Rationale of study, objective, significance and beneficiaries of the study is described in this chapter. Chapter two contains the literature on background of the study and techniques used to monitor deformation. Further, this chapter explains some terms used in this study and summarizes the previous researches on monitoring in relation to this study. Chapter three contains the detailed methodology undertaken in the research. This chapter presents the methods and techniques that will used in gathering data for the study. Chapter four analyses the results as well as discussing them also the chapter describes the tools and ways in which the collected data were processed and analyzed. Chapter five present the conclusions and recommendations basing on the objectives of the study

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Due to fast growing of technology increase of large engineering has facilitate deformation surveys on these structures such as dams, bridges, building, underground tunnel, reservoirs tanks and mine pit undergo deformation, due to overloading, aging, every day tear and wear, crustal movement, ocean tides, stress and erosion (Erol et al., 2014). If the deformation is sufficient enough,it could cause structural failure and cost much loss of lives and properties. Therefore, it is necessary to monitor and analyze the deformation effects and movements of any sizeable civil engineering structures to ensure their safety and security.

2.2 Deformation surveying technology Techniques.

There are several techniques for measuring the deformations. These can be grouped mainly into two categories, geodetic and non-geodetic techniques.

2.2.1 Geodetic surveying

This includes Global Position System (GPS), close range Photogrammetry, terrestrial surveying (leveling, theodolite, total station and very long baseline interferometer) and satellite laser ranging (SLR). Geodetic surveys, through a network of points interconnected by angles and distances measurements, usually supply a sufficient redundancy of observations, for the statistical evaluation of their quality and for detection of errors. They give global information on the behavior of the deformable object. Recent advances in technology have made it possible to use accurate surveying equipment to measure and monitor the deformation of structural members. The emergence of reflector less accurate total station allows working without special reflectors (prisms). It is now possible to measure without long and tedious search of prisms to lift the reflector under the roof of buildings. The principle of work of a reflectorless total station is the same as that of a simple total station.

2.2.2 Non-Geodetic Technique.

This technique involves photogrammetry, laser scanning, tilt and inclination measurement.

i. Photogrammetry.

This technique allows the determination of ground displacements over a long period of time, by comparing the corresponding sets of aerial photographs. If an object is photographed from two or more survey points of known relative positions (known coordinates) with relative orientation of the camera(s) relative position of any identifiable object points can be determined from the geometrical relationship between the intersecting optical rays, which connect the image and object point. ii. Tilt and inclination measurement.

Tilt is determination of deviation from the horizontal plane while inclination is interpreted as a deviation from the vertical. The same instrument that can measures tilt at a point can be called either a tiltmeter or inclinometer depending on the interpretation of the result.

iii. Laser scanning.

This technique is used to monitor large structural engineering such as buildings, viaducts, dams, and bridges in which accuracy is greatly hindered by their low point density. Ground based laser scanning is a new technique that allows rapid, remote measurement of millions of points, thus providing an unprecedented amount of spatial information, thus permitting more accurate prediction of the forces acting on the structure (Paul, 2017).

2.3 Types of Geodetic Network for Deformation Monitoring

2.3.1 Absolute Network

This network is designed such that some geodetic monuments are assumed to be outside the deformable body (reference point) and others on the deformable body (object point) so this is mainly for monitoring small scale engineering structure i.e. dams, bridges and buildings. In absolute networks some of the points are assumed to be outside the deformable body (object) thus serving as reference points (reference network) for the determination of absolute displacements of the object points as shown in Figure 2.1

2.3.2 Relative Network

All geodetic points are assumed to be located on the deforming body. Also, the point is stable (placed) but moving with the body. In the relative network all the surveyed points are considered to be deforming as shown in figure 2.1. It is mainly for large areas.

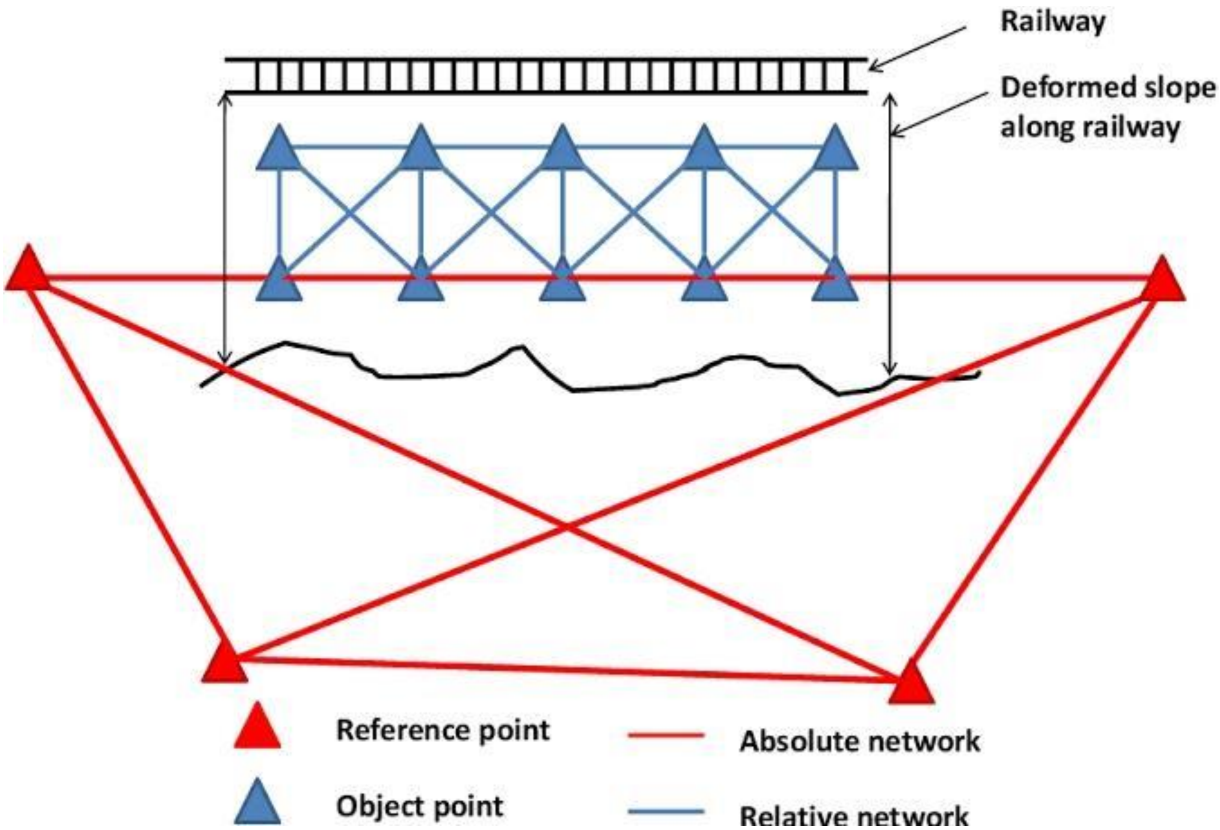


Figure 2.1: Relative and Absolute Network

(Aydın, C., 2014. *Geodetic Deformation Analysis* .YTU Geodesy Division.)

2.4 Monitoring plan.

This is concerned with developing a monitoring system that will be used during the deformation surveys. For this reason, each monitored structure should have a surveying scheme and instrumentation scheme, which is included in the monitoring plan with intended performances as shown in Figure 2.2. In addition, separate designs should be completed for the instrumentation plan and for the proposed measurement scheme.

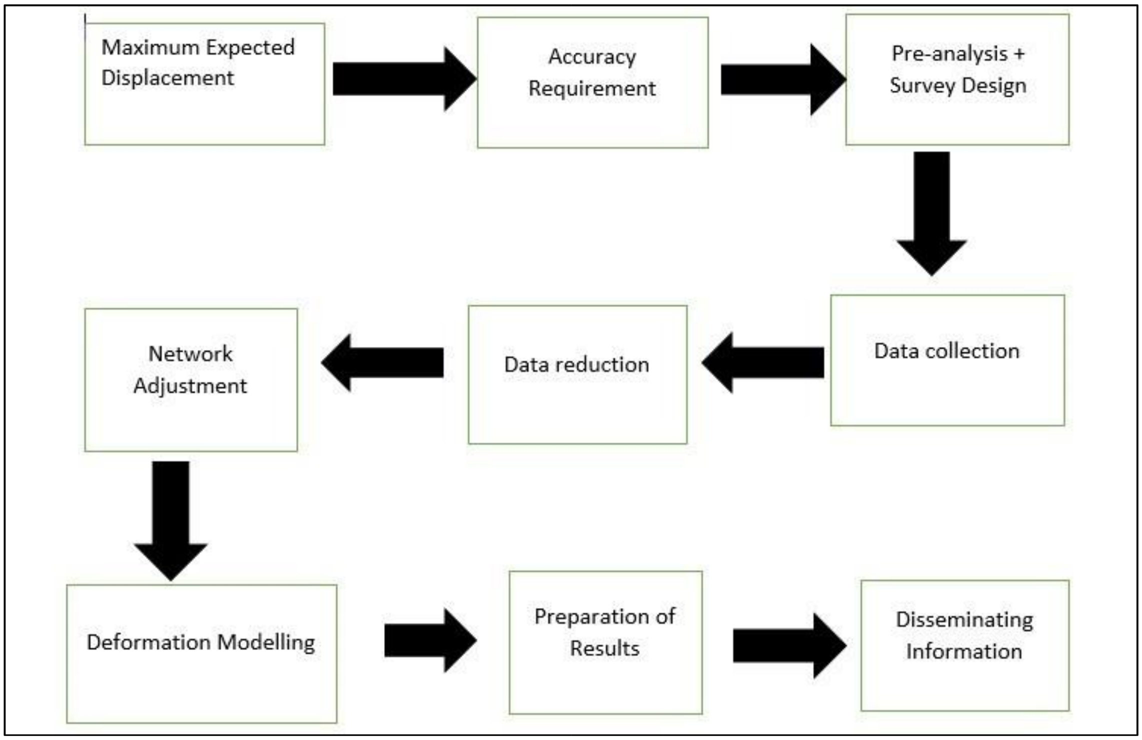


Figure 2.2: Deformation Monitoring Data Flow

2.5 GPS deformation monitoring technology and its difference with other methods.

Global Positioning System currently offers more than one method for structural monitoring applications. Two end-members of these methods may be described as static post-processing of GPS data and Real-Time Kinematic (RTK) positioning. Due to the high precision of the carrier phase measurements, the Global Positioning System (GPS) technology has been widely used for measuring crustal motion, river level and ground subsidence, and more recently for monitoring deformation of man-made structures such as bridges, dams, buildings, etc. It is well known that for such GPS-based deformation monitoring systems, the accuracy, availability, reliability and integrity of the positioning solutions is heavily dependent on the number and geometric distribution of satellites being tracked. However, in some situations, such as in urban canyons, dam monitoring in valleys and in deep open-cut mines, the number of visible satellites may not be sufficient to reliably determine precise coordinates. Furthermore, look in figure 2.3 it is impossible to use GPS for indoor applications. (Abdullahi, 2016)

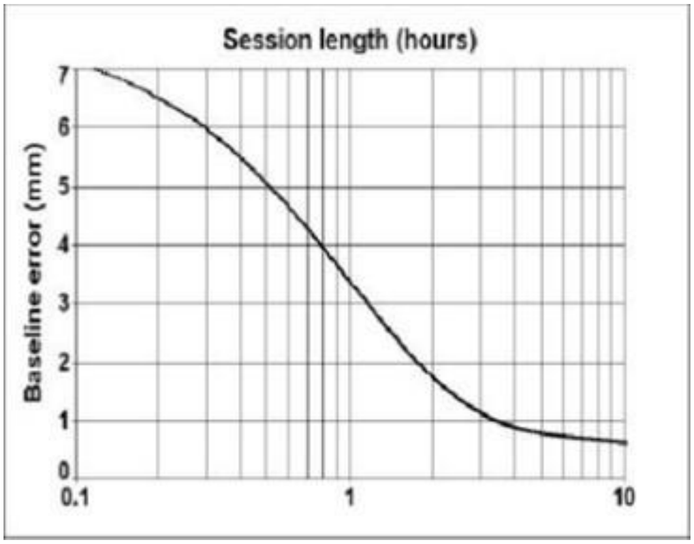


Figure 2.3: GPS coordinates component repeatability in 15 minutes' lessons over a short baseline (Abdullahi 2016).

CHAPTER THREE

METHODOLOGY

3.1 Reconnaissance

Reconnaissance is usually the initial planning stage, which guides the surveyor in determining the appropriate instruments method of data acquisition, to forecast/prepare for circumstances that may spring up in the course of executing any survey project. It requires site visit, checking for existing control points, and office work that includes collection of coordinates which the work to be tied (Abdullahi, 2016). The existing situation of Ruvu Bridge is that it can carry more than one thousand vehicles per day and few pedestrians pass during the daytime. The area along the river contains few trees; also, the height of the Bridge from the ground is approximately 12 meters.

Several deformation contributors were observed on the bridge, which include number, size and cargo exerted by vehicles passing on the bridge, seasonal flood per annum, which seems to deteriorate the strength of the bridge. This shows that monitoring of deformation on the bridge is inevitable. Carefully monitoring of a structure and its response to them can aid in determining abnormal behavior of this structure. During a field visit one nearby bench mark was found named BM01 as shown in figure 3.1

Figure 3.1: Benchmark (BM 01)

Also, during field observation, the existing reference and objective points were observed. The coordinates were as follows in Table 3.1

Table 3.1 Existing control points in UTM (WGS84) and Elevation from MSL

Station	N (m)	E (m)	Elevation	Remark
EM01	9260853.670	465401.413		Reference station
EM03	9257315.715	470834.688		Reference station
RV01	9260483.057	466199.039	21.399	Objective station
RV02	9260443.763	466236.171	21.718	Objective station
RV03	9260410.351	466268.127	21.466	Objective station
RV04	9260417.241	466275.728	21.308	Objective station
RV05	9260489.910	466206.529	21.457	Objective station
RV06	9260489.916	466206.522	21.202	Objective station

In field reconnaissance, all existing control points except EM02 and EM04 were identified physically and object points were identified physically as shown in figure 3.2

i.e. EM01, EM03, RV01, and RV02 etc.

Figure 3.2: Object Control Point RV02

In addition, datum check was performed so as to examine if the reference stations of the reference network are in situ or not and if the establishment of the precision meet the intended purpose.

3.2 Instruments for Data Capture

Selection of instruments used during data acquisition was based on accuracy of establishment of vertical and horizontal control and monitoring of the structure together with availability of the instruments and tools for accomplishing this research. On the other hand, these instruments have been used during pre-analysis to evaluate standard error within the instruments.

In this study, the instruments used include digital level DNA03, Colida K5 plus GPS receiver, footplate, steel tape and tripod

3.3 Pre-Analysis

Pre-analysis is the analysis of the component measurements of a survey project before it 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 instrument, to plan measurements procedure and to provide basics for evaluation of accuracy of survey measurement. In this study two instruments aforementioned in previous section 3.2 i.e., digital level, Colida K5 plus GPS receiver were examined so as to understand their maximum tolerance that can be expected when used during deformation analysis.

3.3.1 Expected Standard Deviation in Determining Differences in Elevation of Levelling Line

Expected Standard Deviation in Determining Differences in Elevation of Levelling Line

From Leica digital level DNA03 specifications, the accuracy (standard deviation) in determining difference in elevation of a leveling line (route) is 1mm for a loop of 1km.

By linear interpolation method,

$$1000m \rightarrow 1mm$$

$$338.0305m \rightarrow \text{x}$$

$$\frac{338.0305mx1mm}{1000m} = 0.3380305mm$$

Therefore, the expected standard deviation in determining difference in elevation is 0.3380305mm.

However, error in measurement according to first and second researchers were 0.525mm 0.326302mm respectively

3.4 INSTRUMENTATION

Look in the table 3.2 below shows Survey instruments and equipments used in this research data collection

Table 3.2 Survey instruments and equipments used in this research data collection

S/No	INSTRUMENT
1.	Leica DNA03 Digital level
2.	Foot plate
3.	Bar coded staff
4.	Steel tape
5.	KOLIDA K5 Plus receiver set
6.	Tripod stands
7.	Machete
8	Hammer
9.	Iron pins
10.	Booking sheets and pencil
11	TS015 Total station
12	360 Prism

3.4.1 Digital level.

This instrument is designed to operate by employing electronic digital image processing. After leveling the instrument, its telescope is turned toward a special bar-coded rod and focused. At the press of a button, the image of bar codes in the telescope's field of view is captured and processed. This processing consists of an onboard computer comparing the captured image to the rod's entire pattern, which is stored in memory. When a match is found, which takes about 4 sec, the rod reading is displayed digitally. It can be recorded manually or automatically stored in the instrument's data collector (Charles & Worlf, 2012).In this research Leica DN03 precise digital level Shown in figure 3.3 was used for leveling procedure.

Figure 3.3: Leica DN03 precise digital level used in this research leveling (Wikipedia)

3.4.2 Tripod stand

Leveling instruments, whether tilting, automatic, or digital, are all mounted on tripods. A sturdy tripod in good condition is essential to obtain accurate results. Several types are available. The legs are made of wood or metal, may be fixed or adjustable in length, and solid or split. All models are shod with metallic conical points and hinged at the top, where they connect to a metal head. An adjustable leg tripod is advantageous for setups in rough terrain or in a shop, but the type with a fixed-length leg may be slightly more rigid. The split-leg model is lighter than the solid type, but less rugged. (Wolf, 2012). In this research the adjustable legs tripod was used

3.4.3 Leveling staff/rod.

A variety of level rods are available, an example is shown in the figure below. They are made of wood, fiberglass, or metal and have graduations in feet and decimals, or meters and decimals. The staff may be in one or more sections. On one side of the staff is a binary bar code for electronic measurement, and on the other side there are often conventional graduations in meters. The black and white binary code comprises many elements over the staff length. The scale is absolute in that it does not repeat along the staff. As the correlation method is used to evaluate 20 the image, the elements are arranged in a pseudo-random code. The code pattern is such that the correlation procedure can be used over the whole working range of the staff and instrument. Each manufacturer uses a different code on their staffs therefore an instrument will only work with a staff from the same manufacturer (Breach, 2007).In this research staff with two sections was used. On one side of the staff is a binary bar code for electronic measurement, and on the other side there are often conventional graduations in meters. Since precise leveling was supposed to be done,a bar code for the electronic side was used.

3.4.4 Global Navigation Satellite System (GNSS)

GNSS is the standard generic term for Satellite Navigation System that provides autonomous geospatial positioning with global coverage. GNSS allows small electronic receivers to determine their location (latitude, longitude and ellipsoidal height) to within a few meters using signal transmitted along a line of sight by radio from the sight. Receivers on the ground, with fixed position can also be used to calculate the precise time as a reference for scientific experiments. The GNSS includes three main satellite technologies: such as GPS, Glonass, and Galileo. Each of them consists mainly of three segments: space segment, control segment and user segment. As of today, the complete satellite technology is the GPS technology and most of the existing worldwide applications related to the GPS technology. In this work the type of GNSS receivers used are KOLIDA receivers.

3.5 Leveling observation

3.5.1 Two Peg Test

The purpose of the two-peg test is to check that the line of sight through the level is horizontal. To perform the two-peg test, two pegs were placed on a flat ground at a distance of 80 m apart as shown in the figure 3.4 below.

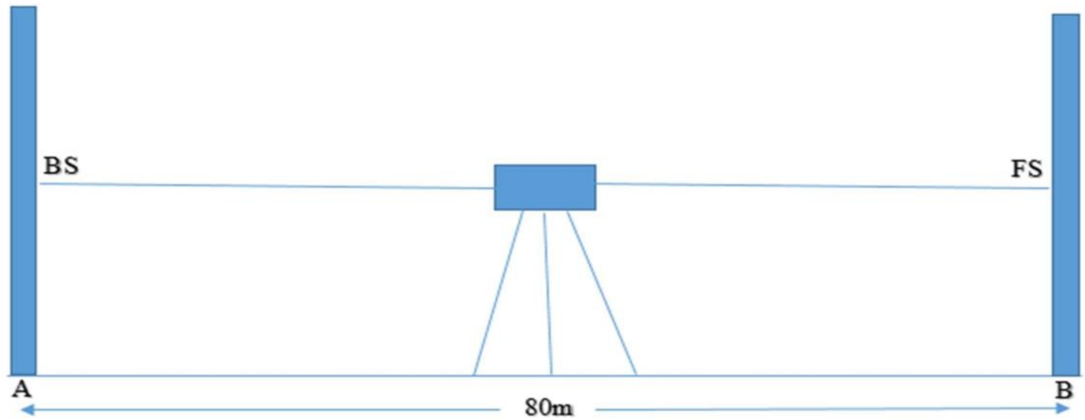


Figure 3.4: Diagram illustrating two-peg test

The instrument is set at the middle of two staff and observations made on both staffs. If the line of sight through the level is not horizontal, the errors in staff readings (e) at both points A and B as shown in figure 3.5 are identical because the level is halfway between the points. The errors are identical, so the calculated difference in elevation between points A and B (difference in staff readings) is the true difference in elevation

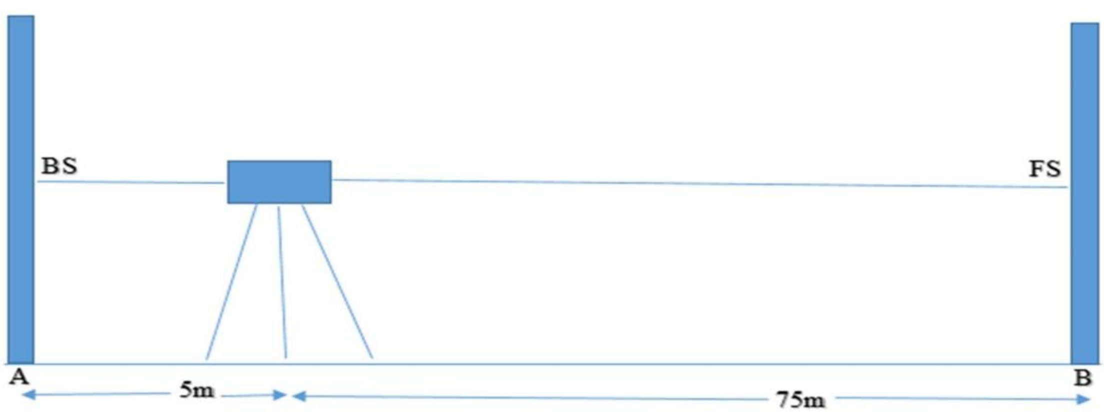


Figure 3.5: Two-peg test with total station placed near back sight

Level is then set close to point A and both readings were taken at staff A and B. Since distance from A to the level is very small then any staff reading error introduced using this very short sight relatively insignificant.

Mathematical models:

$\Delta h1 = (A1 + e) - (B1 + e) = A1 - B1$ … … … …. ……………………………………………(3.1)

$\Delta h2 = (A2) - (B2 + e) = A2 - B2 + e$ … … … … … ………………………………...........(3.2)

but Δh1 = Δh2

Thus eqn (1) = eqn (2)

$A1 - B1 = A2 - B2 + e$

Therefore magnitude of collimation error is given as

$e = (A1 - A2) + (B2 - B1)$

$e = (1.362 - 1.521) + (1.463 - 1.303)$

$e = 0.001$m

3.4.2 Leveling Procedures

The work for leveling commenced after testing of collimation error by two-peg test and the following procedures were involved.

The level machine was set between the bench marks BM01 and the first change point PN1 and then staff readings for back sight at the bench mark and fore sight at the first change point were recorded in the booking sheet as shown in figure 3.7

This proceeded for whole route through points PN1, RV4, RV5, RV6, RV1, RV2, RV3, PN2, PN3 and then closing at BM01

The back sight distances and the fore sight distances were maintained nearly equal so as to reduce or cancel the effect of collimation error.

In all setups, it was assured that all circular bubbles were well leveled both circular bubble in the staff and circular bubble in the level machine as shown in figure 3.6

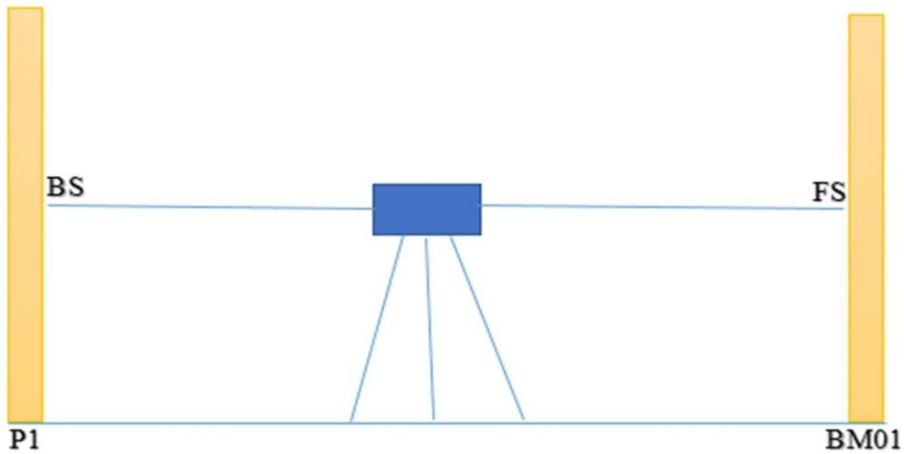


Figure 3.6: Diagram set up for the first station

Reduced level of point PN1 is obtained as follows

RLP1 = RLBM01 $+a - b$

Where “a” and “b” are staff readings at BM01 and PN1 respectively

Figure 3.7: Leveling observation on the site

Table 3.3 A Levelling data of fourth epoch from MSL

POINT ID	BACK SIGHT (m)	FORE SIGHT (m)	Differences BS-FS (m)	REDUCED LEVEL (m)
BM01	2.163			19.193
PN1	2.006	0.623	1.54	20.733
RV 4	1.747	1.436	0.57	21.303
RV5	1.507	1.595	0.152	21.455
RV6	1.465	1.76	-0.253	21.202
PN2	1.538	1.305	0.160	21.362
RV1	1.807	1.497	0.041	21.403
RV2	1.540	1.487	0.32	21.723
RV3	1.293	1.790	-0.25	21.473
PN3	1.118	2.213	-0.92	20.553
BM01		2.478	-1.36	19.193
	$\sum \boldsymbol{B.S} = \mathbf{16.184}$	$\sum \boldsymbol{F}.S = \mathbf{16.184}$		
Check		$\sum \boldsymbol{B.S} - \sum \boldsymbol{F.S}$=0		$\sum \boldsymbol{R.Lf} - \sum \boldsymbol{R.Li} = \mathbf{0}$

3.6 RE-ESTABLISHMENT OF THE NETWORK

3.6.1 Existing Control Points

In the case of horizontal deformation monitoring, the previous researchers had established four control points far away from the Ruvu Bridge (5.6 km) since they used a static method to monitor. These control points were selected based on their proximity to the bridge and their stability as shown in the table 3.4. They were specifically chosen to serve as reference points for measuring horizontal displacements.

Table 3.4 Existing reference points in UTM (WGS84)

POINT ID	NORTHING (m)	EASTING (m)
EM01	9260853.670	465401.413
EM02	9261510.618	466058.456
EM03	9257315.715	470834.688
EM04	9258196.167	471217.103

Two horizontal epochs (2018 and 2020) were obtained by using this method and the same network which were established by Mobil, 2018.

Due to the thief habit, some of reference points were damaged so that they can take iron pin for business, those points are EMO2 and EMO4

In this study, a different method called Tacheometry was used whereby a Total station instrument, the TS015 model, was utilized. The TS015 total station is known for its high precision in angular and distance measurements, making it suitable for accurately capturing horizontal displacements. Since this method is in need of TS015 total station, then new network was established close to Objective Points(420m), then through this network which was established by using GPS, new coordinates were obtained with Point ID as PT01, PT02, PT03 and PT04.

3.6.2 GPS observation

3.6.2.1 Network design

Absolute monitoring network designed by google earth software and was considered to meet the requirements for absolute Deformation Monitoring network. GPS observations were carried after designing the monitoring network. Type of network designed was Absolute monitoring network whereby the monitoring points are RV01 RV02 RV03 RV04 RV05 and RV06 ,these points were installed on the bridge. The monitoring points are installed away from the deforming body i.e PTO1,PT02,PT03 and PT04 .The network was designed as shown below in figure 3.8

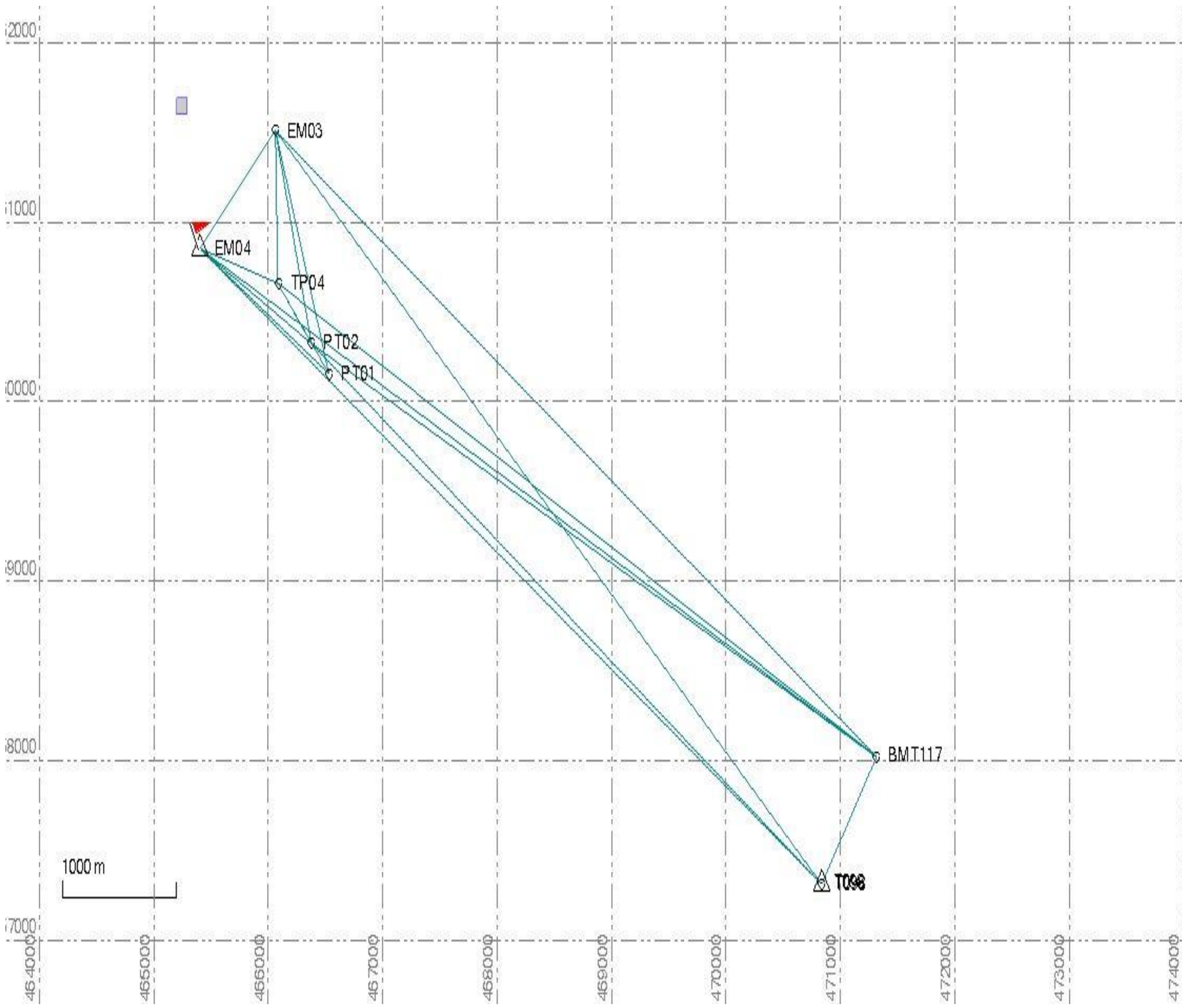


Figure 3.8 Horizontal Network

3.6.3 Monumentation.

Double beacon monumentation; Two survey marks which were placed in the ground so that one is vertically above the other to define the position of a common point. A hole of 45cm was dug and an iron pin of about 25 cm was inserted in the ground up to 10cm, the center point the pin was maintained of using optical plummet mounted on the tripod stand, concrete was used to hold still the pin; the separation of 5cm was kept using glass and soil. The second iron pin of 25cm was then guided using an optical plummet to maintain the center of the built-in pin and built-in concrete as shown in figure 3.9. The points which double beacon monumentation performed are PT01, PT02, PT03 and PT04.These are the monitoring points.

Figure 3.9 Monumentation

Figure 3.10: Static GPS receiver

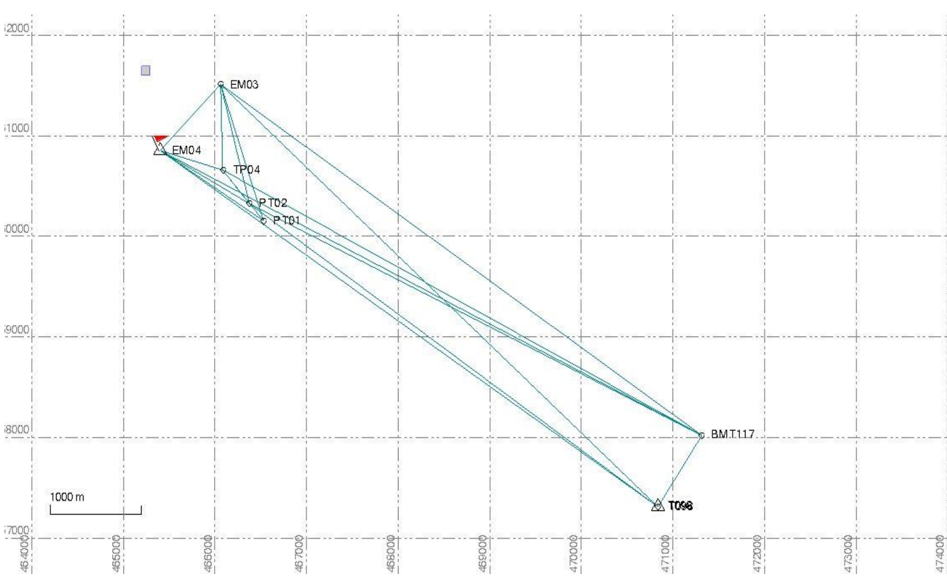


Figure 3.11 Network of reference points tied with control TO96 and EM04

Table 3.5 Adjusted Grid Coordinates in UTM (WGS84) and Ellipsoidal Elevation

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
BMT117	471315.649	0.006	9258026.970	0.006	38.241	0.024	
EM03	466060.414	0.002	9261512.777	0.002	-3.968	0.014	
EM04	465401.413	Fixed	9260853.670	Fixed	0.022	0.015	EN
PT01	466525.521	0.002	9260157.150	0.003	-10.040	0.014	
PT02	466374.709	0.002	9260328.773	0.003	-6.993	0.014	
T098	470834.731	0.012	9257315.719	0.010	40.001	0.028	
TP04	466080.813	0.002	9260661.925	0.003	-6.195	0.011	

Horizontal positions on the monitoring points EM03, EM04, PT01, PT02, BMT117, T098 and PT04 were established by using GPS observation in static mode with a minimum of 1 hour in a session at a specified point. GPS observations were performed by using Colida K5 plus GPS receiver, and in the table 3.5 are the results

3.7 DATA PROCESSING

Static GPS data in RINEX format were joined of the same observation file to get a full file throughout the observation, renamed to a single file then checked for their quality using TBC. After that the static data were processed and adjusted using TBC software and finally the coordinates were in WGS84.

3.7.1 GPS Data Quality Check

Quality check for GPS observation data is basically important as it compares the actual observed data versus standard observed data if there were no problems during observation. This ensures the quality and standard of the observed data before post processing. These comparisons are in percentage, and if the percentage is below 60% the observations are regarded as poor, and above 80% they are excellent. In this work all targeted reference points

PT01 and PTO2 have quality above 90% showing that the observations were of the high quality/excellent as shown in the figure 3.12 below

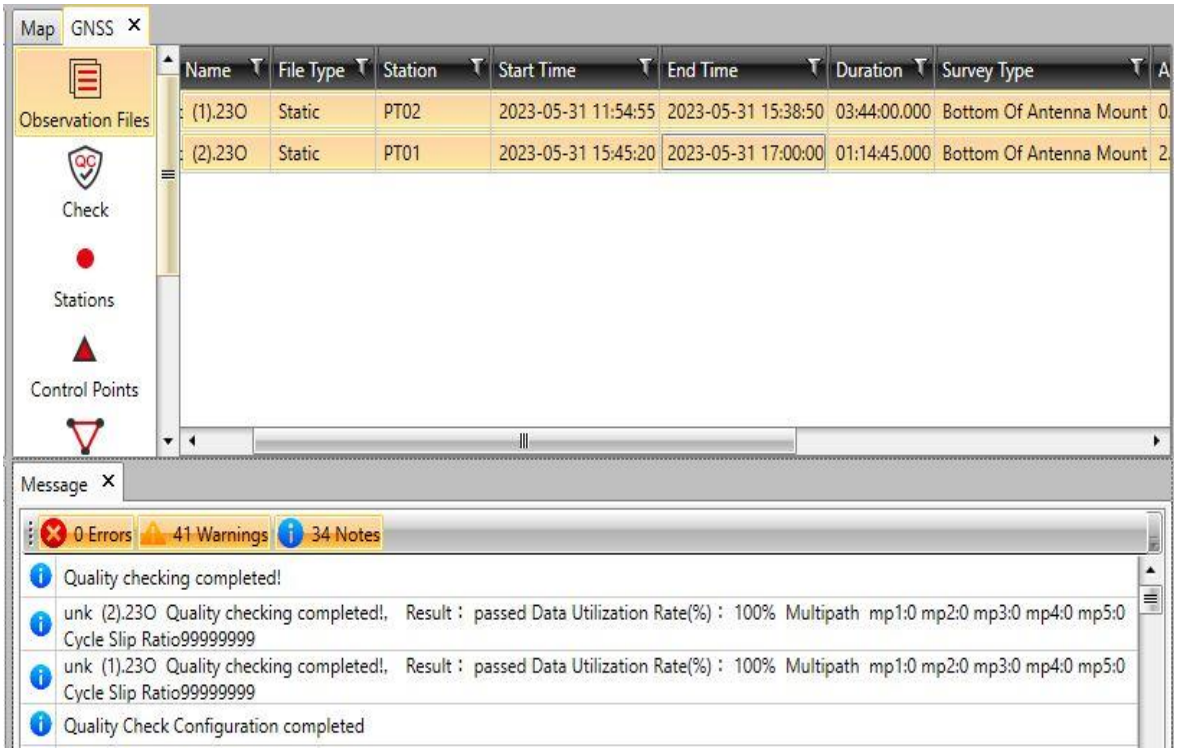


Figure 3.12 Shows the quality check for points PT01 and PT02 which is 100%

Table 3.6 Result of new reference points in UTM (WGS84)

POINT ID	NORTHING (m)	EASTING (m)
PT01	9260157.150	466525.521
PT02	9260328.773	466374.709

These two points in the Table 3.6 were used as opening traverse whereby the instrument was set up on PT02 and orient to PT01 to see if they are in-situ as shown in the figure 3.12 “a” and “b”

(a) (b)

Figure 3.12(a) TS015 Total station set up at point PT02 orient to point PTO1, and Figure 3.12(b) 360 Prism at orientation point PT01

After checking these points, and confirmed that they are in-situ, then observation started; and finally obtained the following results as shown in table 3.7

Table 3.7 Results obtained by TS015 Total station in UTM (WGS84)

POINT ID	NORTHING (m)	EASTING (m)
RV01	9260483.1551	466199.0189
RV02	9260443.7778	466236.1853
RV03	9260410.4335	466268.1185
RV04	9260417.2610	466275.6987
RV05	9260489.995	466206.497
RV06	9260489.9994	466206.4749

These observations are termed as first horizontal epoch

CHAPTER FOUR
RESULTS AND DISCUSSION

This chapter presents discussion and analysis of results. This involves processing and refinements of raw data, reduction, misclosure check and adjustment of the data to obtain the final products that were used for analysis by the next surveys.

4.1 Closure Tolerance Check

It is important to understand the amount of misclosure in leveling. This can be assessed by either connecting the leveling back to the BM from which it started or by connecting the leveling to another BM of known and proved values. The misclosure check is used to decide whether the misclosure is acceptable or not for further analysis. Alternatively, the permeable criteria may be based on distance leveled or number of setups. The common criteria to assess misclosure is given by $E = \pm m\sqrt{k}$, where K is the leveled distance in km and m varies depending on the order of the leveling and its application. For this study, the total distance was 0.3380305Km and the value of m is (m=3), therefore the allowable misclosure is 1.7442 From the observations with results misclosure of 0mm this shows that the results are within the allowable tolerance and can be used for deformation analysis.

4.2 Comparison of results

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

This is mathematically given by

Displacement = $P_{\text{4th epoch}} - P_{\text{3rd epoch}}$ where $P_{4th\ \text{epoch}}$ is the position of the fourth epoch and $P_{3rd\ epoch}$ is the position of the third epoch.

4.3 Analysis of vertical deformation

To assess vertical deformation of the Bridge, the magnitude of displacement should be obtained by subtracting the reduced levels of the fourth epoch from that of the third epoch as shown in the table 4.1 (i.e. third epoch-fourth epoch). The research was done 31st May 2023 to establish fourth epoch that will be used with the third epoch which has performed on 21th July 2020 by David

The magnitude of displacement does not mean the Bridge deforms, but there are factors to be considered to conclude on deformation. The main factor is the allowable tolerance computed during pre-analysis. The comparison of the computed magnitude against the surveying accuracy indicates whether the movement is likely due to survey error. Finally, this comparison will be used to conclude on whether the Bridge deforms or not $d_n < e_n$.

where d_n is the magnitude of the vertical displacement for a point "n" given by $d_n = \sqrt{\Delta H^2}$

e_n = max dimension of combined 95% confidence ellipse.

For a point n, $e_n = 1.9599\sqrt{\Delta\sigma^2}$ and $\Delta\sigma^2$ is the standard error in position (Caspary & Rüeger, 1987).

From $\Delta\sigma = \sigma_{\Delta h}$ where $\sigma_{\Delta h}$ is obtained from pre analysis in section 3.3.1 of chapter three

Thus,

$$e_n = 1.9599 \times 0.3380305mm$$

$$e_n = 0.662505977mm$$

Table 4.1 Difference in levels between the third and fourth epoch

PID	THIRD EPOCH 21st July 2020 (T.E) (m)	FOURTH EPOCH 31st May 2023(F.E) (m)	DISPLACEMENT (F.E-T. E) (m)
RV01	21.399	21.403	0.004
RV02	21.722	21.723	0.001
RV03	21.468	21.473	0.005
RV04	21.313	21.303	0.010
RV05	21.462	21.455	0.007
RV06	21.203	21.202	0.001

4.3.1 Magnitude of vertical displacement for Deforming points

For point RV01

Magnitude of vertical displacement $d = \sqrt{4^2} \ = 4mm$

i.e. d < e

$$\rightarrow \ 4mm < 0.662505977mm$$

These results shows that the vertical component exceed the expected survey error bound, this shows that RV01 deformed

For point RV02

Magnitude of vertical displacement $d = \sqrt{1^2} \ = 1mm$

i.e. d < e

$$\rightarrow\ 1mm < 0.662505977mm$$

These results shows that the vertical component does not exceed the expected survey error bound, this shows that RV02 deformed

For point RV03

Magnitude of vertical displacement $d = \sqrt{5^2}\ = 5mm$

i.e. d < e

$$\rightarrow\ 5mm < 0.662505977mm$$

These results shows that the vertical component does not exceed the expected survey error bound, this shows that RV03 deformed

For point RV04

Magnitude of vertical displacement $d = \sqrt{10^2}\ = 10mm$

i.e. d < e

$$\rightarrow\ 10mm < 0.662505977mm$$

These results shows that the vertical component does not exceed the expected survey error bound, this shows that RV04 deformed

For point RV05

Magnitude of vertical displacement $d = \sqrt{7^2} = 7mm$

i.e. d < e

$$\rightarrow\ 7mm < 0.662505977mm$$

These results shows that the vertical component does not exceed the expected survey error bound, this shows that RV05 deformed

For point RV 06

Magnitude of vertical displacement $d = \sqrt{1^2} = 1mm$

i.e. d < e

$$\rightarrow\ 1mm < 0.662505977mm$$

These results show that the vertical component does not exceed the expected survey error bound, this shows that RV05 deformed.

4.4 GLOBAL CONGRUENCE TEST

The reliability of detecting the object movements depends essentially on the realization of a stable monitoring network around the interesting object. For this reason, the stability of the network points has to be tested with congruence tests as to possible differences between the two epochs

From

$$F = \frac{d^T Q_{dd}^{-1}\, d}{SoF}$$

Whereby ;

d = displacement of the two epochs

d^T= Transpose of d

Q_{dd} = Covariance matrix

Since in this study the residual is 0.0mm, then Q_{dd}^{-1} will used as identity matrix

So = Standard deviation from Pre-analysis

F = Degree of freedom

For RV01

d = [4]m , d^T = [4]m , Q_{dd} = [1]m , So = 0.3380305mm and F is given as follows: -

For the current epoch which is fourth epoch;

Number of epochs = 4

Number of unknow epoch before the current one = 1

$f2 = 4 - 1$

$f2 = 3$

For the third epoch

Number of epochs = 3

Number of unknow epoch before the third one = 1

$f1 = 3 – 1$

$f1 = 2$

Therefore, the degree of freedom(F) = f1+f2

F = 2+3

F = 5

Then from,

$$F = \frac{d^T Q_{dd}^{-1}\, d}{SoF}$$

$$Fm = \frac{[4][1][4]}{0.3380305 \times 5}$$

Fm = 9.466601387

Fd obtained from F – Distribution by 95%

Whereby f1 = 2

f2 = 3

Fd = F 2,3,0.05 = 9.55

Fd >Fm

These results shows that the theoretical value exceed the actual value, this shows that RV01 is not deformed

RV02

d = [1]m , d^T = [1]m , Q_{dd} = [1]m , So = 0.3380305mm and F = 5

$$Fm = \frac{[1][1][1]}{0.3380305 \times 5}$$

Fm = 0.591662586

From the F – Distribution by 95%

Whereby f1 = 2

f2 = 3

Fd = F 2,3,0.05 = 9.55

Fd >Fm

These results shows that the theoretical value exceed the actual value, this shows that RV02 is not deformed

RV03

d = [5]m , d^T = [1]m , Q_{dd} = [5]m , So = 0.3380305mm and F = 5

$$Fm = \frac{[5][1][5]}{0.3380305 \times 5}$$

Fm = 14.79156467

From the F – Distribution by 95%

Whereby f1 = 2

f2 = 3

Fd = F 2,3,0.05 = 9.55

Fm >Fd

These results shows that the theoretical value does not exceed the actual value, this shows that RV03 deformed

R04

d = [10]m , d^T = [1]m , Q_{dd} = [10]m , So = 0.3380305mm and F = 5

$$Fm = \frac{[10][1][10]}{0.3380305 \times 5}$$

Fm = 59.16625867

From the F – Distribution by 95%

Whereby f1 = 2

f2 = 3

Fd = F 2,3,0.05 = 9.55

Fd <Fm

These results shows that the theoretical value does not exceed the actual value, this shows that RV04 deformed

RV05

d = [10]m , d^T = [1]m , Q_{dd} = [10]m , So = 0.3380305mm and F = 5

$$Fm = \frac{[7][1][7]}{0.3380305 \times 5}$$

Fm = 28.99146675

From the F – Distribution by 95%

Whereby f1 = 2

f2 = 3

Fd = F 2,3,0.05 = 9.55

Fd <Fm

These results shows that the theoretical value does not exceed the actual value, this shows that RV04 deformed

RV06

d = [1]m , d^T = [1]m , Q_{dd} = [1]m , So = 0.3380305mm and F = 5

$$Fm = \frac{[1][1][1]}{0.3380305 \times 5}$$

Fm = 0.591662586

From the F – Distribution by 95%

Whereby $f1 = 2$

$f2 = 3$

$Fd = F_{2,3,0.05} = 9.55$

$Fm < Fd$

These results shows that the theoretical value exceed the actual value, this shows that RV02 is not deformed

4.5 Time Series Analysis

A time series is a sequential set of data points recorded over regular time intervals. In the context of the research on "Re-establishment and Vertical Monitoring Deformation" at the Ruvu Bridge, time series analysis plays a crucial role in understanding the behavior of the structure over time.

By plotting the displacement data from six objective points RV01,RV02,RV03,RV04,RV05 and RV06 on the bridge, researchers can identify patterns and trends that might not be immediately apparent from static measurements. The time series analysis aids in recognizing repetitive variations, seasonal influences, and long-term trends in the displacement data.

Moreover, it facilitates the detection of anomalies or irregularities, which can be essential in understanding potential structural issues or external factors affecting the bridge's stability. Furthermore, time series analysis allows researchers to make predictions and forecasts about future displacements, aiding in maintenance planning and ensuring the bridge's safety. Overall, incorporating time series analysis in the research adds a dynamic dimension, providing a comprehensive and insightful perspective into the vertical monitoring deformation at the Ruvu Bridge.

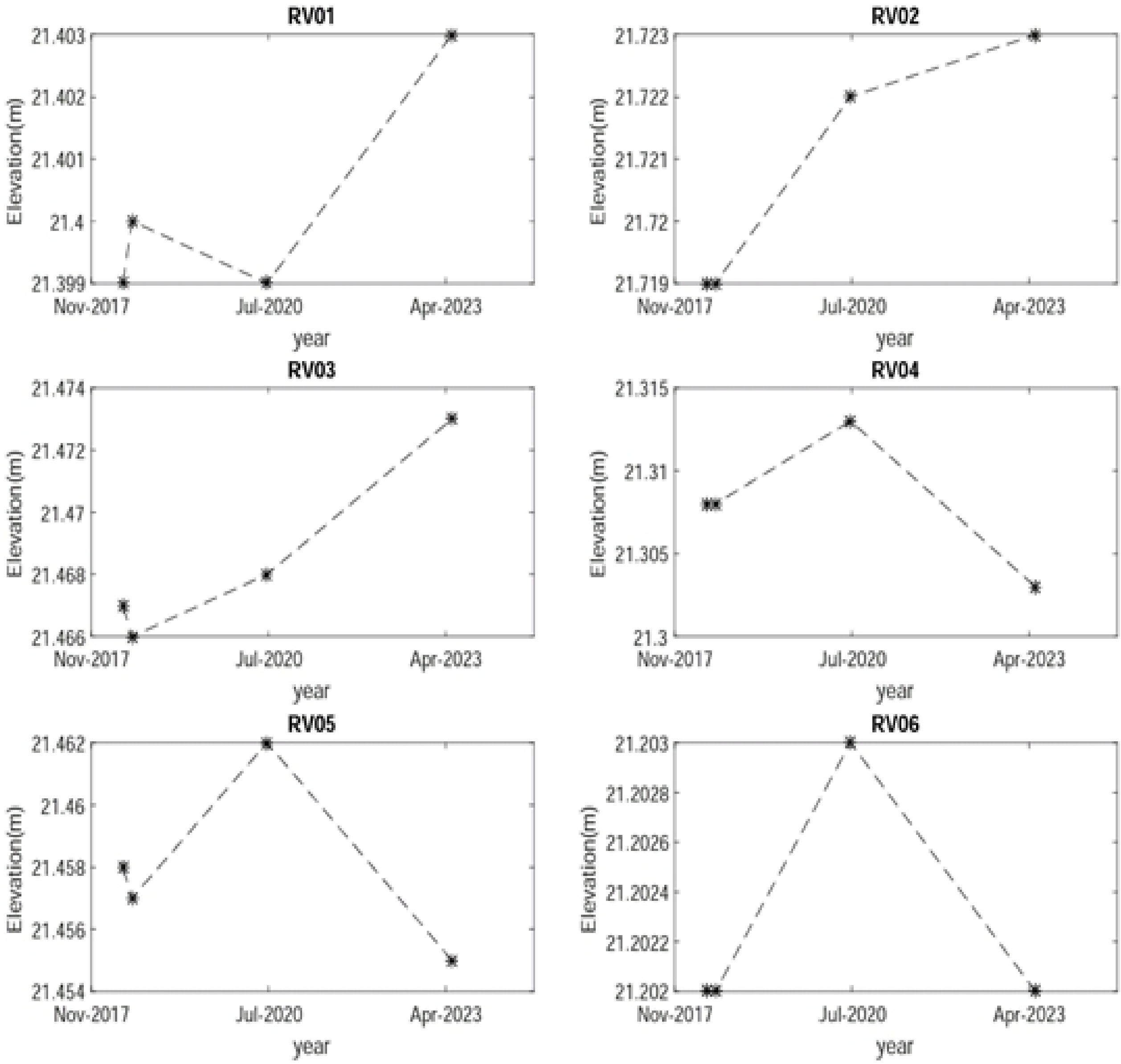


Figure 4.1 Time Series of vertical deformation data for Ruvu Bridge since 2018 up to 2023.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study has monitored and analyzed vertical deformation of Ruvu Bridge and re-establish horizontal network of Ruvu Bridge. Where vertically it has achieved leveling route of distance of 338.0305 meters and the misclosure of 0.000mm, which was within the allowable range ±0.3380305mm obtained from pre-analysis

The evaluated vertical displacement magnitudes were compared with their corresponding computed 95% confidence intervals to determine the significance of the movements. Genarally, It was found that some of the objective points RV03, RV04 and RV05 is deforming by rate 1.667mm/year,3.333 mm/year and 2.333 mm/year respectively

These results show that vertical displacement of the bridge is critical to public safety and the nation's economy for the fifty years to come

5.2 Recommendation

From results analysis and conclusions made above, it is therefore recommended

i. To ensure safety and security of Ruvu Bridge, deformation monitoring should be done regularly at least after each six months so as to have enough deformation data for Ruvu Bridge in order to assess for structural deformation of a structure.

ii. Since only one epoch is not enough for deformation monitoring, then second horizontal epoch should done

iii. Establishment of more reference control points since only one benchmark is not enough to give redundant observation

REFERENCES.

Aydin, C. (2014). Geodetic Deformation Analysis. Ytu Geodesy Division.

Beshr, A. A. (2015). Structural Deformation Monitoring and Analysis of Highway Bridge using Accurate Geodetic Techniques. Science Resources ,Vol 2, 16-18.

Chandra, D. A. (2005). Surveying Problem Solving with a Theory and Objective Type Questions. New Delhi: New Age International (P) Ltd.

Choudhury, J. R., & Hasnat, A. (August 2015). Bridge Collapse around the World: Causes and Mechanisms.

Emmanuel, M. (2018). NETWORK DESIGN AND DEFORMATION MONITORING OF THE RUVU BRIDGE. Dar Es Salaam: Ardhi University.

Erol, B. E., & Ayan, T. (May 2014). A General Review of the Deformation Monitoring Techniques and A Case Study : Analysing Deformation using GPS/ LEVELLING.

Hui, M. R. (2009). Monitoring of Bridge Deformation using GPS Techniques KSCE. Journal of Civil Engineering.

Joseph, T. S. (2019). Monitoring Deformation of Machinga Complex of Overhead Bridge. Dares-Salaam: Ardhi University.

Kalkan, Y. (2002). Structure Deformation Survey . US Army Corps of Engineers.

Kapovic, Z. (2005). Deformation monitoring of the bridges by conventional and GPS methods.
595-603. .

Mwalongo, V. (2015). Monitoring of Vertical Structural Deformation of Overhead Bridge. Acase Study Machinga Complex. Dar-es-Salaam: Ardhi University.

Paulo, N. (2017). Assessment of Vertical Motion of DAWASCO Reservior Tank at Lower Ruvu using Precise Leveling and Differential GNSS Technique. Dar-es-Salaam: Ardhi University.

Pendaeli, J. (2017). Monitoring Structural Deformation of Overhead Bridge. A case of Machinga Complex Bridge. Dar-es-Salaam: Ardhi University.

Schofield, W., & Breach, M. (2007). Engineering Surveying, 6th Edition. Elsevier Ltd.

Yelwa, N., & Abdullahi, A. (2016). Structural Deformation Monitoring Survey of New Administration Building of Federal School of Survey. Oyo-Nigeria.

Koch, K. R.: Parameter Estimation and Hypothesis Testing in Linear Models. Springer, Berlin and New York, 1999.

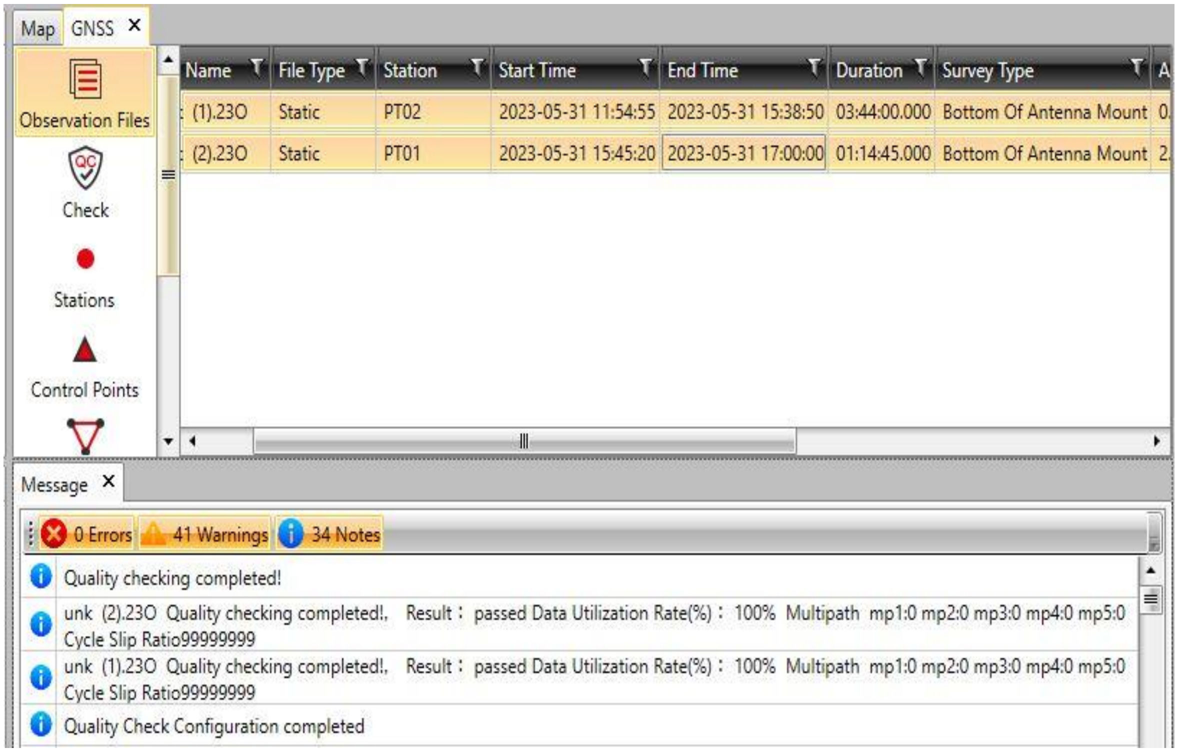
Kutterer, H.: Statistical Hypothesis tests in case of imprecise data, in: F. Sanso (Ed.): Proceedings of the 5. Hotine-Marussi-Symposium. International Association of Geodesy Symposia, Springer, Berlin and New York, 2004.

APPENDICES

APPENDIX I: Levelling data

POINT ID	BACK SIGHT (m)	FORE SIGHT (m)	Differences BS-FS (m)	REDUCED LEVEL (m)
BM01	2.163			19.193
PN1	2.006	0.623	1.54	20.733
RV 4	1.747	1.436	0.57	21.303
RV5	1.507	1.595	0.152	21.455
RV6	1.465	1.76	-0.253	21.202
PN2	1.538	1.305	0.160	21.362
RV1	1.807	1.497	0.041	21.403
RV2	1.540	1.487	0.32	21.723
RV3	1.293	1.790	-0.25	21.473
PN3	1.118	2.213	-0.92	20.553
BM01		2.478	-1.36	19.193
	$\sum \boldsymbol{B.S} = \mathbf{16.184}$	$\sum \boldsymbol{F}.S = \mathbf{16.184}$		
Check		$\sum \boldsymbol{B.S} - \sum \boldsymbol{F.S}$=0		$\sum \boldsymbol{R.L\,f} - \sum \boldsymbol{R.Li} = \mathbf{0}$

APPENDIX II: Quality data check for PT01 and PT02



APPENDIX III: SURVEY STATION DESCRIPTION CARD FOR POINT PT01

GPS SURVEY LOGSHEET **Date: ____________________**

Observer's Name/s: ____

Point ID: _________________ Antenna Height: __________ Antenna Offset: ___________

Receiver Type: _____________________ Receiver S/N: __________________

Battery Capacity: Battery 1: _________ Battery 2: ___________External__________

Controller Type: ________________ Controller SN: ________________

Latitude: __________________ Longitude: _____________________ Height: __________

Location: _________________ District: _______________ Region: ___________________

Start Time (Local): ____________________ End Time (Local): ___________________

Start Time (UTC): _____________________ End Time (UTC): ___________________

LOCATION SKETCH

APPENDIX IV: SURVEY STATION DESCRIPTION CARD FOR POINT PT02

GPS SURVEY LOGSHEET **Date: ____________________**

Observer's Name/s: ____

Point ID: _________________ Antenna Height: __________ Antenna Offset: ___________

Receiver Type: _____________________ Receiver S/N: __________________

Battery Capacity: Battery 1: _________ Battery 2: ___________External__________

Controller Type: ________________ Controller SN: ________________

Latitude: __________________ Longitude: _____________________ Height: __________

Location: _________________ District: _______________ Region: ___________________

Start Time (Local): ____________________ End Time (Local): ___________________

Start Time (UTC): _____________________ End Time (UTC): ___________________

LOCATION SKETCH

APPENDIX V: SURVEY STATION DESCRIPTION CARD FOR POINT PT03

GPS SURVEY LOGSHEET **Date: ____________________**

Observer's Name/s: ____

Point ID: _________________ Antenna Height: __________ Antenna Offset: ___________

Receiver Type: _____________________ Receiver S/N: __________________

Battery Capacity: Battery 1: _________ Battery 2: ___________External__________

Controller Type: ________________ Controller SN: ________________

Latitude: __________________ Longitude: _____________________ Height: __________

Location: _________________ District: _______________ Region: ___________________

Start Time (Local): ____________________ End Time (Local): ___________________

Start Time (UTC): _____________________ End Time (UTC): ___________________

LOCATION SKETCH