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APPLICATION OF FINITE ELEMENT TO DEFORMATION MONITORING OF PHYSICS DEPARTMENT BUILDING IN THE UNIVERSITY OF BENIN, UGBOWO, CAMPUS, EDO STATE, NIGERIA

BY

OKOIBHOLE JOHN OSEMUDIAMEN

ENV1805817

A PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE (B.SC) DEGREE IN GEOMATICS, AT THE UNIVERSITY OF BENIN, BENIN CITY, NIGERIA.

A PROJECT SUBMITTED TO THE DEPARTMENT OF GEOMATICS, FACULTY OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF BENIN, BENIN CITY.

APRIL, 2024

CERTIFICATION

This is to Certify that this work was carried out by **OKOIBHOLE OSEMUDIAMEN,** Mat No. ENV1805817, of the Department of Geomatics, Faculty of Environmental Science, University of Benin, Edo State Nigeria.

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EXTERNAL SUPERVISOR DATE

DEDICATION

This project is dedicated to the Almighty God for His love, care and provisions in all times of need.

ACKNOWLEDGEMENT

I want to sincerely thank everyone who contributed to the successful completion of my project. This project has been a journey full of obstacles and successes, and I am incredibly appreciative of the help and advice I have received.

I owe a debt of gratitude to my project adviser Engr. Professor Ralph Ehigiator-Irughe, R, for his unwavering support, constructive criticism,insights and corrections have been vital to the project's success,his constant commitment to research and academic success has served as a constant source of motivation.

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Lastly, I am grateful to my colleagues and close friends;

ABSTRACT

This study explores the application of Finite Element Analysis (FEA) in monitoring structural deformations affecting the Physics Department building at the University of Benin, Ugbowo Campus. Structural deformation poses significant challenges to the integrity and safety of buildings, especially in regions where environmental and mechanical stressors are prevalent. As a building ages, undetected shifts or weaknesses in its foundational and support elements can lead to long-term damage or even collapse. By applying FEA, engineers can model how structures respond under various conditions, enabling a more data-driven and predictive approach to building assessment and rehabilitation.

The research employs high-precision instruments such as the Tersus David GNSS receiver and a NUWA-configured mobile application to collect geospatial data with exceptional accuracy. Strategic GNSS receiver placement and real-time data acquisition were crucial to capturing the building's current geometric integrity. This data was further processed, and key mechanical parameters such as displacement, strain, and stiffness matrices were also computed. The finite element method enabled segmentation of the structure into triangular meshes, which were individually analyzed to detect irregularities.

Beyond immediate technical benefits, this study offers lasting academic and institutional value. The insights gathered contribute to the field of Geomatics and structural engineering by presenting a viable case study for integrating FEA and

GNSS technologies in infrastructure monitoring. The findings also serve as a foundation for ongoing observation and maintenance of the building, helping to prevent future deterioration and reinforcing the need for continuous structural health monitoring in Nigerian universities and beyond.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

It is known from a geological perspective that regions prone to seismic activities require vigilant deformation monitoring to assess .The fundamental objective of deformation surveys is to maintain the structural stability of various constructions, ranging from dams and bridges to buildings and infrastructure. Early detection through advanced surveying techniques facilitates timely intervention, enabling engineers to address potential issues before they escalate into catastrophic failures. By employing precise measurement techniques, such as GPS, total stations, and leveling instruments, deformation surveys provide valuable insights into the stability and integrity of structures, terrain, and geological formations.

An essential element of investigating deformation involves grasping the connections between stress and strain in materials. Stress denotes the force exerted per unit area, whereas strain signifies the consequent deformation. Grasping the correlation between stress and strain assists in characterizing a material's response to varying loads and circumstances. This understanding is pivotal in engineering endeavors, ensuring that materials can endure projected stress levels without experiencing failure.

Central to the rationale for deformation surveys is the imperative of ensuring the safety of structures and the lives of those associated with or residing near these structures.

The importance of deformation studies cannot be underestimated. There have been different scenarios in which structure collapses all over the world. Examples of these collapses are:

the construction site on Gerrard Road, Ikoyi on the 1st of November 2021, which led to the deaths of scores of people.

The Nigeria Association of Geodesy (NAG) identified lack of deformation surveys for monitoring of structures as the major factor responsible for frequent building collapse in Lagos state. Scientists and researchers that specializes in scientific areas of surveying have agree that the absence of deformation surveys for monitoring of structures such as high-rise buildings, bridges and dams is responsible for the frequent building collapse in Lagos and other cities.

Other notable Historical events such as the collapses of the Ojiani dam in Akoko-Edo and the Tiga dam in Kano State, underscore the dire consequences of neglecting deformation monitoring. Systematic surveys serve as proactive measures, allowing engineers to identify signs of instability and implement corrective actions, thereby mitigating the risk of structural failures and safeguarding lives and properties.

Deformation surveys extend beyond structural safety to encompass broader environmental considerations. Changes in landscapes and geological formations can have far-reaching effects on ecosystems, water bodies, and surrounding environments. Unchecked deformations may lead to alterations in water flow patterns, habitat disruptions, and soil erosion. Systematic monitoring contributes to sustainable environmental management, aiding in the preservation of ecosystems and the mitigation of potential environmental hazards.

Recent advancements in surveying technologies, including satellite-based monitoring systems, LiDAR (Light Detection and Ranging), and advanced sensors, have revolutionized the precision and efficiency of deformation surveys. These technologies provide real-time data and detailed insights into structural behavior, enabling engineers to conduct comprehensive analyses and make informed decisions regarding maintenance and structural improvements.

In conclusion, the background of this study underscores the indispensable role of deformation surveys in preserving the stability of structures, landscapes, and geological formations. By elucidating the importance of monitoring deformations and their profound impact on safety and environmental sustainability, this study sets the stage for a deeper exploration of proactive surveying practices. Incorporating cutting-edge technologies ensures that deformations are identified early, allowing for timely interventions and contributing to the longevity and resilience of the built and natural environment.

1.2 STATEMENT OF THE PROBLEM

From our initial Observations The main issue with the physics department building deformation is the displacement of certain pillars supporting the structure within the physics lab's equipment storage. the University of Benin's Physics department has existed for over a decade, but despite this there hasn't been anything put in place for adequate monitoring of the structure. This project aims to obtain baseline data for future deformation observation, addressing the lack of proper scrutiny of the building. Structural deformation in the physics department building poses a range of issues that jeopardize the safety, functionality, and durability of both the building and its infrastructure. These problems can be attributed to factors like material fatigue, external forces, environmental conditions, or design deficiencies.

The following are some prevalent problems linked to structural deformation:

1. Structural deformation can lead to a compromise in the overall stability and strength of the building, posing a potential risk of collapse or failure.
2. Deformation may result in unsafe conditions for occupants, visitors, or passersby, increasing the likelihood of accidents, injuries, or fatalities.
3. Deformation can adversely affect the functionality of the building, causing disruptions to daily operations, hindering productivity, and impeding the intended use of spaces.
4. Persistent structural deformation accelerates wear and tear, reducing the expected lifespan of the building and necessitating premature maintenance or reconstruction.
5. Dealing with the aftermath of structural deformation incurs significant financial burdens, including repair costs, potential legal liabilities, and the economic impact of downtime.
6. Visible deformations may compromise the aesthetic appeal of the structure, impacting its visual integrity and potentially diminishing property values.
7. Structural deformations can contribute to environmental hazards, such as the release of hazardous materials or the disruption of natural habitats, with broader implications for sustainability.
8. Businesses or academic activities housed within the deformed structure may experience

disruptions, leading to operational inefficiencies and potential setbacks.

9. Structural issues resulting from deformation can lead to a decline in property value, affecting not only the immediate stakeholders but also the surrounding community.

10. Instances of structural deformation may give rise to legal liabilities, as property owners or stakeholders may be held accountable for damages or injuries caused by the compromised structure.

1.3 AIMS AND OBJECTIVES OF THE STUDY

The aim of this project is the Application of Finite Element to Deformation monitoring of the Physics Department Building.

OBJECTIVES;

These are the following objectives:

1. To create a database for the Monitoring of the structure.
2. To use a finite element to determine the deformation of the structure.
3. To serve as a base study for the future observations and monitoring.

1.4 SCOPE OF STUDY

The scope of this project entails a comprehensive examination of the deformation issues affecting the Physics Department Building within the University of Benin. The study focuses on a range of critical aspects to provide a thorough understanding of the structural changes occurring within this significant academic facility,

1. The study will involve a detailed assessment of the Physics Department Building to identify and quantify deformations. This encompasses both visible deformations and those that may be concealed, requiring a thorough analysis of the entire structure.

2. The project will explore and employ cutting-edge deformation monitoring technologies. Advanced sensors, data analytics, and real-time monitoring systems will be integrated to ensure accurate and timely data collection on structural changes.

3. The scope encompasses a comprehensive safety and risk assessment associated with identified deformations. Potential hazards to occupants and the surrounding environment will be evaluated, and risk mitigation strategies will be developed accordingly.

4. Based on the findings, the project will propose recommendations for effective mitigation strategies. These recommendations will prioritize the preservation of the building's structural integrity, occupant safety, and the longevity of the facility.

1.5 JUSTIFICATION OF STUDY

This research holds substantial relevance for the field of Geomatics and structural monitoring. Applying Finite Element Analysis (FEA) to the deformation monitoring of the Physics Department building enables a more proactive approach to structural integrity assessment. It strengthens the foundation for predictive maintenance by identifying deformation patterns early and allowing informed decision-making regarding renovations or reinforcements.

The study contributes both academically and practically, enriching the existing body of knowledge and demonstrating how GNSS-integrated FEA methods can be implemented for real-world infrastructure. Additionally, the project supports institutional compliance with safety standards and affirms the university's commitment to innovation, sustainability, and structural resilience.

Ultimately, the justification for this research is rooted in the need to ensure safety and functionality in academic structures, especially as they age. Deformation monitoring using modern tools not only protects infrastructure investments but also provides a repeatable framework for universities across the country seeking to modernize their infrastructure surveillance system.

CHAPTER TWO

LITERATURE REVIEW

2.1 DEFORMATION MONITORING

Deformation monitoring is a crucial aspect of structural health monitoring, as it enables the detection of subtle changes in shape or dimension that can indicate potential structural issues. This is particularly important in critical infrastructure such as bridges, dams, and high-rise buildings, where structural failure can have catastrophic consequences. Deformation monitoring allows engineers to identify issues early, enabling proactive maintenance and repair, and reducing the risk of structural failure. ***(S. C. Liu and Y. L. Xu, 2018)***

Deformation monitoring is an essential component of construction quality control, as it ensures that structures are built to design specifications and that any deviations are identified and addressed promptly. During construction, deformation monitoring can help identify issues such as settlement, tilt, and deformation, enabling corrective action to be taken before they become major problems. This reduces the risk of costly rework, and ensures that the final product meets the required standards. ***(R. H. McCuen, 2018).***

2.2 TYPES OF DEFORMATION MONITORING

2.2.1 Geodetic deformation monitoring:

This type of monitoring uses geodetic sensors such as levels, total stations, global navigation satellite system (GNSS) receivers, terrestrial laser scanners (TLS), and ground-based synthetic aperture radar (GB-SAR) to monitor deformation, internal stress, seepage, water level, etc. ***(Krauter, 2017)***. Geodetic deformation monitoring is used to measure precise changes in position and orientation of points on the Earth's surface, and is commonly used in applications such as monitoring ground deformation, landslides, and structural health.

2.2.2 Geotechnical deformation monitoring:

This type of monitoring uses instruments such as extensometers, piezometers, pressuremeters, rain gauges, thermometers, barometers, tiltmeters, accelerometers, and seismometers to measure displacements or movements and related environmental effects or conditions ***(Fulton, 2000).*** Geotechnical deformation monitoring is used to measure changes in soil and rock properties, and is commonly used in applications such as monitoring soil settlement, foundation stability, and slope stability.

2.2.3 Manual deformation monitoring:

This type of monitoring involves the manual operation of sensors or instruments by hand or the manual downloading of collected data from deformation monitoring instruments ***(Liu & Xu, 2019).*** Manual deformation monitoring is a simple and cost-effective method, but can be time-consuming and prone to human error.

2.3. CATEGORIES AND CHARACTERISTICS OF DEFORMATION;

Deformation is generally classified into two major types: elastic and plastic. Elastic deformation, as explained by **Hibbeler (2016)**, is reversible and occurs when a material returns to its original form after the removal of stress. In contrast, plastic deformation is irreversible and is typically observed once the stress surpasses the material's yield limit. Other forms include brittle deformation, where materials fracture with little to no plastic deformation, and ductile deformation, whereby the material undergoes significant plastic deformation before failure, allowing for substantial elongation or change in shape. Ductile materials, such as metals, can undergo large plastic deformations without fracturing. **(Callister & Rethwisch 2018)**

2.4. THE IMPORTANCE OF DEFORMATION MONITORING;

Deformation monitoring is a systematic process used to observe and quantify structural movements or shifts over time. It plays a vital role in civil and geotechnical engineering for ensuring public safety and asset longevity. According to **Lienhart and Chrzanowski (2009**), early detection of deformation provides critical data for proactive maintenance and decision-making. In infrastructure such as bridges, dams, and high-rise buildings, monitoring helps to avoid catastrophic failure through timely intervention.

It is also a vital component of modern structural and geotechnical engineering practice, primarily because it serves as both a diagnostic and predictive tool in infrastructure management. As infrastructures age or are subjected to varying environmental loads, internal stress redistributions can cause subtle displacements that often precede structural failure. Monitoring these shifts enables timely interventions that help prevent costly damage or catastrophic collapse **(Chrzanowski et al).**

The primary value of deformation monitoring lies in its ability to function as an early warning system. It allows engineers and decision-makers to detect and interpret subtle structural movements before they become visible or damaging. According to **Wunderlich (1996)**, even minor displacements, if left unchecked, can escalate into critical structural instabilities. Through real-time tracking of deformations, maintenance schedules can be optimized, and resources allocated more effectively.

Technological evolution has vastly improved the precision and reach of deformation monitoring. Traditional geodetic techniques, such as leveling and total station measurements, have now been enhanced by satellite-based systems like GNSS and remote sensing tools like InSAR and LiDAR.

Crosetto et al. (2016) emphasize that the integration of these modern tools has enabled high-resolution, multi-temporal deformation tracking over broad spatial areas, with millimeter-level accuracy.

In public infrastructure such as bridges, dams, and high-rise buildings, the importance of deformation monitoring cannot be overstated. **Chrzanowski et al. (2006)** argue that incorporating monitoring systems into routine structural assessments increases resilience by catching deviations from design parameters early. It provides quantitative insight into how structures age or respond to added stress loads, thereby informing design improvements and future construction standards.

For institutions and academic facilities like the Physics Department building at the University of Benin, deformation monitoring also aids in asset management and long-term sustainability planning. **Casagli et al. (2017)** show that data gathered from systematic monitoring campaigns has been instrumental in prioritizing renovation schedules, securing maintenance funding, and mitigating disruptions caused by unexpected infrastructure failures.

Ultimately, deformation monitoring provides a critical foundation for evidence-based decision-making in structural maintenance, urban planning, and disaster risk reduction. Its embedded role in modern engineering practice is not merely for troubleshooting but for optimizing the full lifecycle performance of infrastructure assets, ensuring safety, and upholding structural reliability across diverse environments.

2.5 DATA PROCESSING AND ANALYTICAL TECHNIQUES

Analysis methods are the foundation of deformation monitoring, as they allow engineers to interpret structural movements, identify patterns, and make informed decisions about the health of a structure. One of the most widely used techniques is time-series analysis, which involves evaluating positional or displacement data collected over consistent time intervals. This method is particularly effective for identifying slow, progressive deformations that may not be immediately apparent in single-epoch observations. **Casagli et al. (2017)** assert that time-series analysis helps detect both linear and non-linear deformation trends and is essential for long-term monitoring programs, especially in complex infrastructures like bridges and institutional buildings.

Once collected, deformation data must be analyzed using robust methods. Time series analysis helps detect patterns, trends, and anomalies in displacement data **(Casagli et al., 2017)**. Advanced modeling tools such as Finite Element Method (FEM) are used to simulate stress distribution and predict deformation behavior under varying conditions **(Cook et al., 2002)**. FEM is especially valuable for forecasting future structural states and understanding stress concentration zones in complex geometry.

Multivariate analysis also plays a role in correlating deformation data with environmental or structural variables, such as temperature, humidity, and load changes. According to **Wunderlich (1996),** this kind of correlation allows engineers to isolate causative factors behind deformation, enabling more precise intervention planning.

With the advancement of sensor technology and data acquisition systems, real-time monitoring and automated data processing have become more accessible. This has shifted deformation analysis toward more dynamic, high-frequency methods. Modern systems often integrate GNSS, total station, and InSAR data with automated software that continuously checks for deviations from expected norms**. Crosetto et al. (2016)** highlight that these integrated systems enable faster decision-making, making them particularly useful in high-risk environments like dams, tunnels, and landslide-prone slopes.

2.6 ANALYSIS METHOD:

Understanding how materials deform under different conditions is crucial in structural engineering. This section presents an overview of deformation analysis methods drawn from recent studies.

2.6.1. *DIGITAL IMAGE CORRELATION (DIC)*

Digital Image Correlation (DIC) is an optical technique for measuring surface deformations by tracking patterns of speckles or markers. DIC provides high-resolution deformation measurements and has applications in material testing **(Huang et al., 2017)** and biomechanics **(Besier et al., 2019).**

2.6.2. *GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)*

Global Navigation Satellite Systems (GNSS) are used for real-time monitoring of structural deformations. By tracking GNSS receiver positions on structures, GNSS can detect subtle movements **(Bisnath & Gao, 2021).** This method has been applied in monitoring infrastructure like dams **(Zhu et al., 2018)** and landslides **(Gili et al., 2020).**

2.6.3. STRAIN GAUGE MEASUREMENT

Strain gauges measure strain in materials under mechanical loading. By attaching them to critical points on a structure, engineers can directly measure strain and infer deformation characteristics

(Yilmaz et al., 2019). Strain gauge measurement is common in laboratory experiments and field tests for validating models and monitoring structural health.

2.7. FINITE ELEMENT ANALYSIS IN DEFORMATION STUDIES

Finite Element Analysis has gained prominence in deformation studies for its ability to model real-world structural responses. It divides the structure into smaller "elements" for which equations of motion or equilibrium are solved, generating high-resolution results of displacement, strain, and stress distribution. **Zienkiewicz and Taylor (2000)** highlighted that FEA's predictive strength lies in its capacity to handle irregular geometries and material heterogeneity, making it a reliable tool for engineering .This approach enables engineers to simulate how materials and structural systems respond to various load conditions with a level of precision that traditional methods cannot match.

In modern deformation studies, FEM is often integrated with real-world geospatial data to validate simulations and improve predictive accuracy. When used alongside GNSS coordinates, tilt readings, and strain gauge data, FEM transitions from a purely theoretical tool into a responsive system that reflects actual structural conditions. This form of hybrid modeling is essential in long-term infrastructure monitoring. **Chrzanowski et al. (2006)** argue that the validation of FEM outputs with empirical data greatly increases confidence in the structural models and supports data-driven maintenance strategies.

Another key advantage of FEM is its adaptability over time. Engineers can update the model as new monitoring data becomes available, essentially turning it into a living representation of the structure. This makes it ideal for proactive maintenance regimes, especially in environments where structural conditions evolve due to environmental stressors or usage patterns. **Zienkiewicz and Taylor (2000)** stress that this adaptability ensures long-term reliability and performance assessments remain aligned with real-world behavior

.

CHAPTER THREE

METHODOLOGY

3.1. LOCATION OF STUDY AREA

The deformation monitoring project was carried out at the Physics Department building located on the Ugbowo Campus of the University of Benin, Edo State, Nigeria. The geographical coordinates of the site are latitude 6.399755°N, 5.615334°E and 6.399720°N, 5.615915°.

Major facilities in my area of interest include: Physical science complex, Mathematics and Geology departments beside my study area and a field. The length of the stretch is 14.369m(0. 12km).

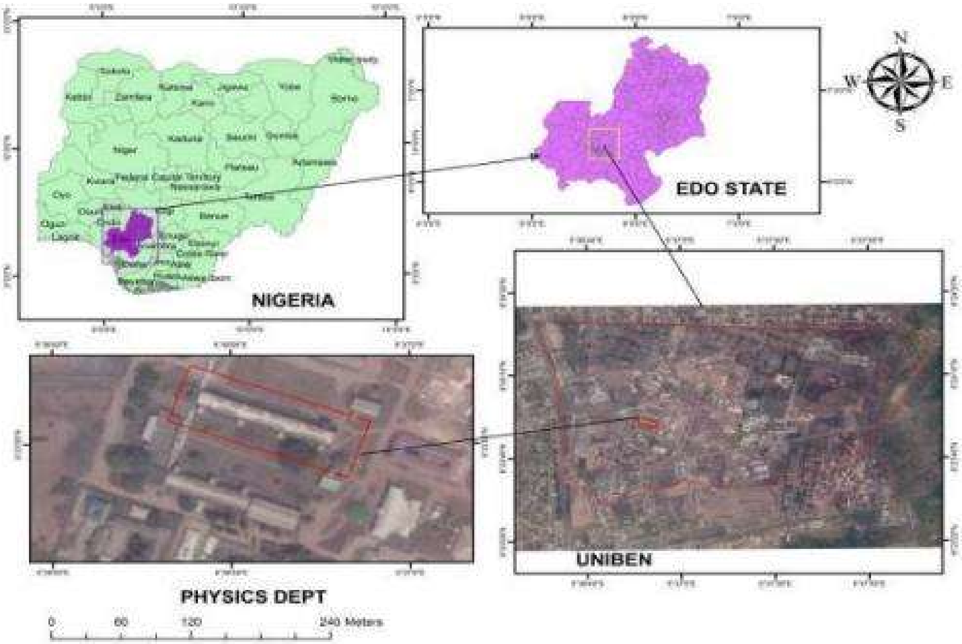


Figure 3.1: showing the study area

Successful deformation monitoring requires thorough planning and reconnaissance. This involved both office-based and field activities.

3.2. OFFICE RECONNAISSANCE;

This included collecting satellite imagery via Google Earth, obtaining the coordinates of control points, and developing a preliminary layout for the site. Existing structural blueprints and spatial data were reviewed to guide point placement and equipment setup.

3.2.2, FIELD RECONNAISSANCE.

The field reconnaissance involved a physical survey of the site. Structural anomalies such as cracks and shifted columns were noted. The perimeter of the building was measured using a 50-meter steel tape. Monitoring points were marked at 50-meter intervals using pegs and markers to serve as GNSS observation points.

3.3 EQUIPMENT AND INSTRUMENTS USED;

The following instruments and tools were used:

1. - Tersus David GNSS Receiver and staff

2. NUWA-configured Android device

3. 50-meter measuring tape

4. Marker and field pegs

5. External power bank

6. HP Intel Core i7 Laptop (16GB RAM)

7. ArcGIS, Microsoft Word, Notepad

3.4 INSTRUMENT SETUP

Before data acquisition, the GNSS device was tested for functionality. The Tersus GNSS rover was mounted on a rod at a height of 180mm and configured via Bluetooth with the NUWA app. The UTM Zone 31N projection and Clarke 1880 ellipsoid were selected, and transformation parameters were set using Bursa-Wolf values The NUWA app was synced with Professor Ehigiator's base station, and a new survey project was initiated. Once connection was secured, observations were taken at each marked point.

3.5 DATA ACQUISITION AND PROCESSING;

Data collection involved capturing GNSS coordinates from multiple fixed points along the building's perimeter over several days. Each point was measured repeatedly to ensure reliability.

This formed a crucial phase in this study, as it provided the empirical foundation for evaluating structural deformation in the Physics Department building at the University of Benin. The methodology combined field-based observations using modern geodetic instruments with post-processing techniques designed to enhance data accuracy and extract meaningful structural insights.

The primary instrument employed for this project was the Tersus David GNSS receiver, configured via the NUWA Android-based mobile application. The GNSS receiver was mounted on a calibrated survey staff and connected to a reference base station — provided by Professor Ehigiator — using Bluetooth. Before field deployment, the receiver and the app were synchronized and initialized to use the Universal Transverse Mercator (UTM) Zone 31N coordinate system with the Clarke 1880 ellipsoid. Transformation parameters were defined using the Bursa-Wolf model to ensure consistency with national geodetic standards.

Data collection was conducted over multiple days to minimize temporal errors and capture reliable readings. Observation points were marked around the perimeter of the building, particularly focusing on areas showing signs of structural anomalies such as cracks or surface displacement. Each point was measured repeatedly at specified intervals to reduce random errors and to establish a baseline for comparative analysis. During each session, the receiver logged precise coordinates (latitude, longitude, and elevation) and stored them within the NUWA app for export.

Following fieldwork, the GNSS data was exported and organized using Microsoft Excel and ArcGIS. A structural monitoring database was created, which included key variables such as point ID, northing, easting, and elevation. From this dataset, positional shifts were computed using vector-based formulas, allowing the identification of both horizontal and vertical displacements. The resulting displacement data served as input for Finite Element Analysis (FEA) simulations carried out later in the study.

3.6. CREATING A STRUCTURAL MONITORING DATABASE;

The collected GNSS data was processed and organized for monitoring. Calculations for displacement, bearing, and relative shifts were conducted. These served as input for Finite Element Analysis (FEA).

The first step involved sorting and cleaning the raw data exported from the NUWA application. Each observation point was tagged with a unique identifier, and corresponding values such as latitude, longitude, elevation, time of observation, and horizontal dilution of precision (HDOP) were recorded. Redundant or inconsistent measurements were filtered out through manual review and statistical averaging, ensuring that only high-quality positional data were retained for further analysis.

Using Microsoft Excel and ArcGIS, a geospatial database was created to house the processed coordinates. The database was structured with multiple fields including:

1. Point ID

2. Northing and Easting (UTM)

3. Elevation (in meters)

4. Time stamp

5. Observation epoch

This format ensured that the dataset was both human-readable and machine-compatible for integration into modeling software. Data validation procedures were also implemented, including range checks for elevation differences and comparison of repeated measurements to detect anomalies or drifts in positioning.

Once the cleaned GNSS data was grouped together, displacement vectors were computed to quantify relative movement between observation periods. These vectors were derived using basic geometric and vector mathematics to measure positional changes in both horizontal and vertical directions. The calculated displacements were stored in the database alongside the original coordinates to provide a complete temporal record of structural behavior.

The next phase involved visualizing the data using GIS and CAD tools, the final database not only served as the input for Finite Element Analysis (FEA) but also functioned as a historical record for continued monitoring.

3.7. FINITE ELEMENT APPLICATION

Using FEA, the building's structure was modeled as interconnected triangular elements. The data was meshed and analyzed to simulate stress-strain behavior. The stiffness matrix and global deformation matrix were computed for each triangle.Using the processed GNSS data — particularly the displacement vectors and elevation changes — the monitored building was modeled as a series of interconnected triangular mesh elements. Each triangle represented a portion of the structural surface, and its vertices were defined using the coordinates of the GNSS observation points. This meshing process allowed for the translation of spatial measurements into a mathematical model that could respond to simulated external forces and internal stress distributions.

To implement the FEM, displacement values from the GNSS database were input as nodal deformations, forming the basis for solving the global deformation matrix. This matrix included essential parameters such as:

1) Element stiffness coefficients

2) Load distribution across the structure

3) Internal strain and stress fields

The governing equations for plane strain deformation were used to compute element-wise behavior. These included both stiffness matrices for each triangular element and nodal displacement vectors, which together formed the global system equation:

$$[K]\{u\} = \{F\},$$

where [K] represents the stiffness matrix, {u} is the displacement vector, and {F} is the applied force vector derived from actual or assumed loading conditions.

3.8. QUALITY ASSURANCE

Redundant observations, calibration checks, and real-time differential corrections were implemented to ensure data integrity. The entire methodology followed standard geomatics surveying protocols to maintain accuracy and reproducibility.To further ensure the credibility of the deformation results, the data was cross-referenced with visual observations and site reconnaissance records. Locations where field cracks were identified were compared against GNSS-measured displacements and FEA results, providing multi-source confirmation of structural instability in those zones.

The methods discussed in this chapter provided a solid foundation for capturing and analyzing deformation in the Physics Department building. From field reconnaissance to data processing and finite element application, each step contributed to a reliable structural monitoring system. With the GNSS data now processed and the simulation model in place.

CHAPTER FOUR

Result and Discussion

4.1 Results

Deformation monitoring using GNSS involves the collection of high-precision position data from satellites to track changes in the Earth's surface over time. This technique offers unparalleled accuracy and reliability, making it indispensable in a wide range of industries, including geology, civil engineering, and infrastructure management.

Field data acquisition typically involves the deployment of GNSS receivers at strategic locations across the area of interest. These receivers continuously track signals from multiple satellites, allowing for the calculation of precise 3D coordinates. By comparing these coordinates over time, analysts can detect even subtle deformations in the monitored area, such as subsidence, uplift, or lateral movement.

Several studies have demonstrated the effectiveness of GNSS in deformation monitoring. For example, research by Sładek Sładeczek, & Jędrysiak, J. (2023) showcased the use of GNSS-based interferometric synthetic aperture radar (InSAR) for monitoring ground subsidence with millimeter-level accuracy. Similarly, the work of Xu, Zhuang, & Yu, (2023) highlighted the utility of GNSS in detecting tectonic plate movements and seismic activity. The tables below shows the different data set for the weeks monitored.

WEEK 1

DAY 1

Pt No	Northing	Eastings	Height
Pt A	708078,5399	789418.3798	167.2492
Pt B	708118.7248	789304.7568	168.3008
Pt C	708137.4274	789309.7724	167.3914
Pt D	708096.7590	7894424. 8422	167.3898

DAY 2

Pt NO	Northing	Easting	Height
Pt A	708078.5725	789418.3337	167.3322
Pt B	7088118.7779	789304.5939	168.6772
Pt C	708137.5112	789309.7491	167.3900
Pt D	708096.7390	789424.8098	167.4128

DAY 3

Pt No	Northings	Eastings	Height
Pt A	708078.5879	789418.3431	167.2980
Pt B	708118.5412	789304.6911	167.8330
Pt C	708137.4540	789309.7673	167.4230
Pt D	708096.8305	789424.8574	167.2586

DAY 4

Pt No	Northings	Eastings	Height
Pt A	708078.6238	789418.2492	167.2596
Pt B	708118.7601	789304.6958	167.5226
Pt C	708138.5659	789310.8936	168.7222

Pt D	708096.6724	789424.7392	167.5408

DAY 5

Pt No	Northings	Eastings	Height
Pt A	708078.6117	789418.3367	167.2750
Pt B	708118.7229	789304.7053	167.4420
Pt C	708137.5743	789309.6701	167.2568
Pt D	708096.7454	789427.8109	167.3234

WEEK 2

DAY 1

Pt No	Northing	Eastings	Height
Pt A	708078.5659	789418.3610	167.5858
Pt B	708118.4860	789304.7073	167.0370
Pt C	708137.6068	789309.7957	168.2600
Pt D	708096.7839	789424.7517	167.3234

DAY 2

Pt No	Northing	Eastings	Height
Pt A	708078.5229	789418.4500	167.2748
Pt B	708118.7446	789304.7117	167.4284
Pt C	708137.4345	789309.8400	167.3788
Pt D	708096.7014	789424.7404	167.3352

DAY 3

Pt No	Northing	Eastings	Height
Pt A	708078.4123	789418.3809	167.1954
Pt B	708118.7394	789304.6800	167.3498
Pt C	708137.7635	789330.8301	167.4720
Pt D	708096.8362	789424.8102	167.2996

DAY 4

Pt No	Northing	Eastings	Height
Pt A	708078.4965	789418.4107	167.3138

Pt B	708118.5808	789304.6463	167.5432
Pt C	708137.5214	789310.0109	167.4030
Pt D	708096.6056	789424.9239	167.3784

DAY 5

Pt No	Northing	Eastings	Height
Pt A	708078.5435	789418.5356	167.3138
Pt B	708118.5858	789304.6514	167.5432
Pt C	708137.5214	789309.9355	167.3788
Pt D	708096.6056	789424.8345	167.3784

Table 4: Showing data collected

4.2 Data Processing and Analysis

The process of monitoring a structure such as dams, reservoir, bridges, buildings, etc using GIS involves collecting and analyzing various and finding different parameters such as the stiffness matrix(K), the distance(l) and the bearing(θ). The parameters contribute greatly to the deformation monitoring analysis on the structure. This process of data analysis involves extracting meaningful information from the collected observations. Data fusion of GNSS data with other geodetic and geophysical datasets to enhance deformation monitoring capabilities. (Kitsakis, Kougioumtzis, & Kapetanidis 2023) Figure 4.2 below represents the section of the building whose deformation status is being considered.

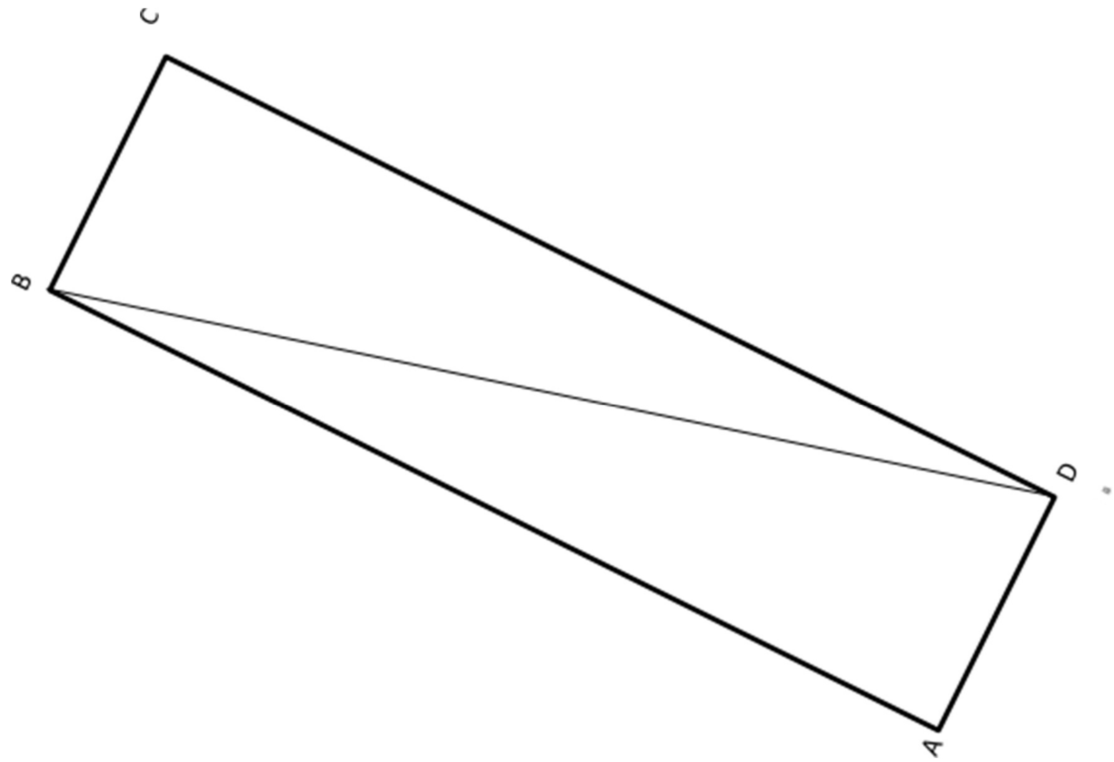


Figure 4.2: Showing the building's cross section

4.2.3 Determination of the Stiffness Matrix of the Elements

The fundamental attributes of a finite element are encapsulated within its stiffness matrix. In the case of a structural finite element, this matrix encompasses both geometric and material properties, providing insight into the element's resistance to deformation under loading. Such deformation can involve axial, bending, shear, and torsional effects (Ehigiator & Irughe, 2019). For finite elements employed in nonstructural analyses like fluid flow and heat transfer, the term "stiffness matrix" is still utilized as it signifies the element's resistance to alteration when subjected to external influences. The equation for the local stiffness matrix is presented in the equation below:

$$K = \frac{EA}{L}\begin{bmatrix} l^2 & lm & -l^2 & -lm \\ lm & m^2 & -lm & -m^2 \\ -l^2 & -lm & l^2 & lm \\ -lm & -m^2 & lm & m^2 \end{bmatrix}$$

Equation 4.1

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

Equation 4.2

WEEK 1

Northings		Eastings	
A	708078.5872	A	789418.3285
B	7080118.705	B	789304.6886
C	708137.7066	C	789309.9705
D	708096.7493	D	789424.8119

Table 4.2.1 showing the average Eastings and Northings for week one

WEEK 2

Northings		Eastings	
A	708078.5082	A	789418.3285
B	708118.6273	B	789304.6793

C	708137.5619	C	789309.6424
D	708096.7027	D	78424.8121

Table 4.2.2 Showing the average Easting and Northings for week two

For Week 1

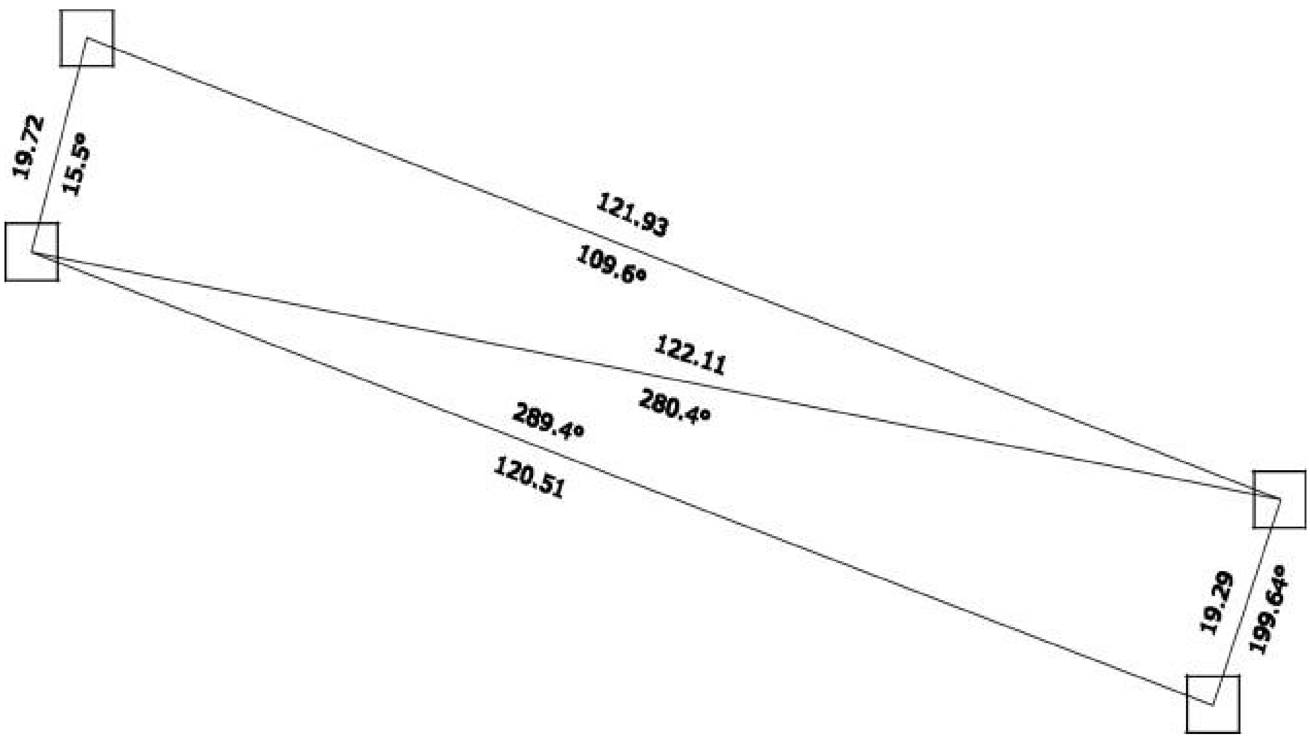
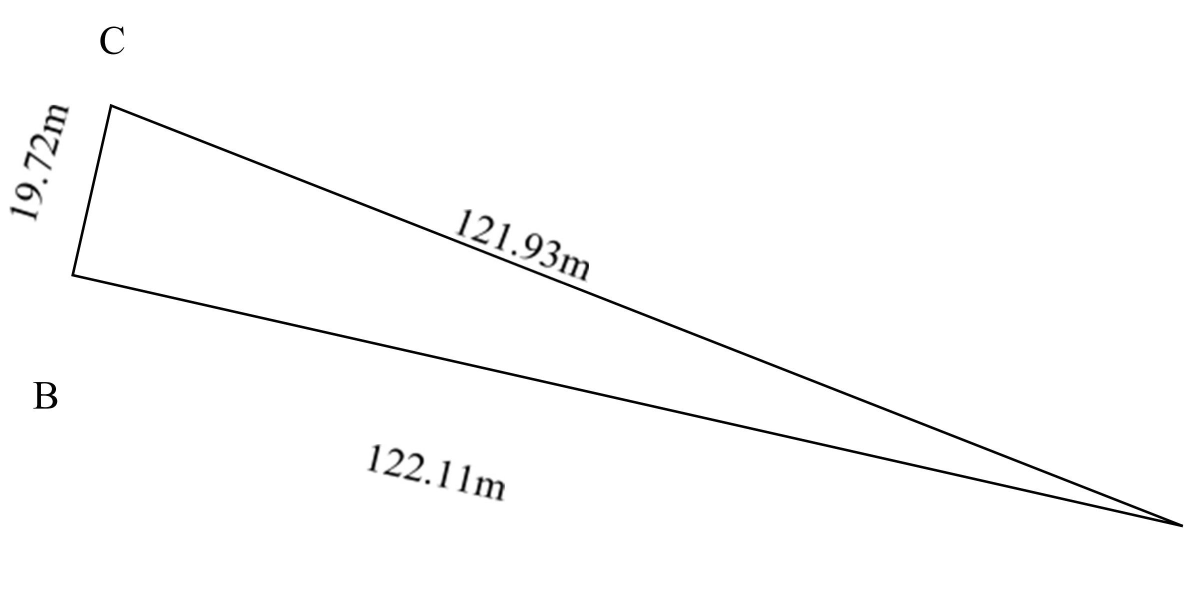


Figure 4.3: Showing the Distance and bearing for data collected in week one



D

Area= $1199.228''^2$

L_1=Lcosθ Equation 4.3.1

M_1=Lsinθ Equation 4.3.2

L_1=19.72cos(15.5)

L_1=19.00

M_1=19.72sin(15.5)

M_1=5.27

$$K = \frac{EA}{L}\begin{bmatrix} l^2 & lm & -l^2 & -lm \\ lm & m^2 & -lm & -m^2 \\ -l^2 & -lm & l^2 & lm \\ -lm & -m^2 & lm & m^2 \end{bmatrix}$$

$$\begin{bmatrix} u_1 & v_1 & u_2 & v_2 \\ 361 & 100.13 & -361 & -100.13 \\ 100.13 & 27.77 & -100.13 & -27.77 \\ -361 & -100.13 & 361 & 100.13 \\ 100.13 & -27.77 & 100.13 & 27.77 \end{bmatrix} \times \frac{210\times1199.228}{19.72}$$

$L_2 = L \cos\theta$

$L_2 = 121.93\cos(109.6)$

$L_2 = -40.9$

$m_2 = L\sin\theta$

$$m_2 = 121.93\sin(109.6)$$
$$m_2 = 114.9$$

$$\begin{bmatrix} u_2 & v_2 & u_3 & v_3 \\ 1672.8 & -4699.41 & -1672.8 & 4699.41 \\ -4699.41 & 13202.01 & 4699.41 & -13202.01 \\ -1672.8 & 4699.41 & 1672.8 & -4699.41 \\ 4699.41 & -14202.01 & 4699.41 & 13202.01 \end{bmatrix} \times \frac{210\times1199.228}{121.93}$$

$L_3 = L \cos\theta$

$L_3 = 122.11 \cos(280.4)$

$L_3 = 22.04$

$m_3 = L \sin\theta$

$m_3 = 122.11 \sin(280.4)$

$m_3 = -120.10$

$$\begin{bmatrix} u_3 & v_3 & u_4 & v_4 \\ 485.76 & -2647.0 & -485.76 & 4699.41 \\ -2647.0 & 14424.01 & 2647.0 & -13202.01 \\ -485.76 & 2647.0 & 485.76 & -2647.0 \\ 2647.0 & -14424.01 & 4699.41 & 13202.01 \end{bmatrix} \times \frac{210\times1199.228}{122.11}$$

Global Matrix

u_1	v_1	u_2	v_2	u_3	v_3	u_4	v_4
361	100.13	-361	-100.13	0	0	0	0
100.13	27.77	-100.13	-27.77	0	0	0	0
-361	-100.13	-167497.46	130502.62	-1672.8	4699.41	0	0
100.13	-27.77	100.13	366619.81	4699.41	-13202.01	0	0
0	0	-1672.8	4699.41	2282785.402	34945720.47	-485.76	2647.0
0	0	4699.41	-13202.01	12439338.27	190425924.3	2647.0	-14424.01
0	0	0	0	-485.76	2647.0	2647.0	-14424.01
0	0	0	0	2647.0	-14424.01	-2647.0	14424.01

Define the 8x8 matrix

```
A = [361, 100.13, -361, -100.13, 0, 0, 0, 0;
     100.13, 27.77, -100.13, -27.77, 0, 0, 0, 0;
     -361, -100.13, -167497.46, 130502.62, -1672.8, 4699.41, 0, 0;
     100.13, -27.77, 100.13, 366619.81, 4699.41, -13202.01, 0, 0;
     0, 0, -1672.8, 4699.41, 2282785.402, 34945720.47, -485.76, 2647.0;
     0, 0, 4699.41, -13202.01, 12439338.27, 190425924.3, 2647.0, -14424.01;
     0, 0, 0, 0, -485.76, 2647.0, 2647.0, -14424.01;
     0, 0, 0, 0, 2647.0, -14424.01, -2647.0, 14424.01];
```

Define the equations B and C

B = (210 * 1199.228 / 263.76)^-1;   Calculate B

C = (54.069 * 10^3);   Calculate C

Multiply matrix A by B and C together

Result3 = A * B * C;   Matrix A multiplied by scalars B and C

Reshape the result into a single column vector
Result_column = result3(;

Display the results as a single column

Disp('The result of multiplying matrix A by B and C as a single column is:');

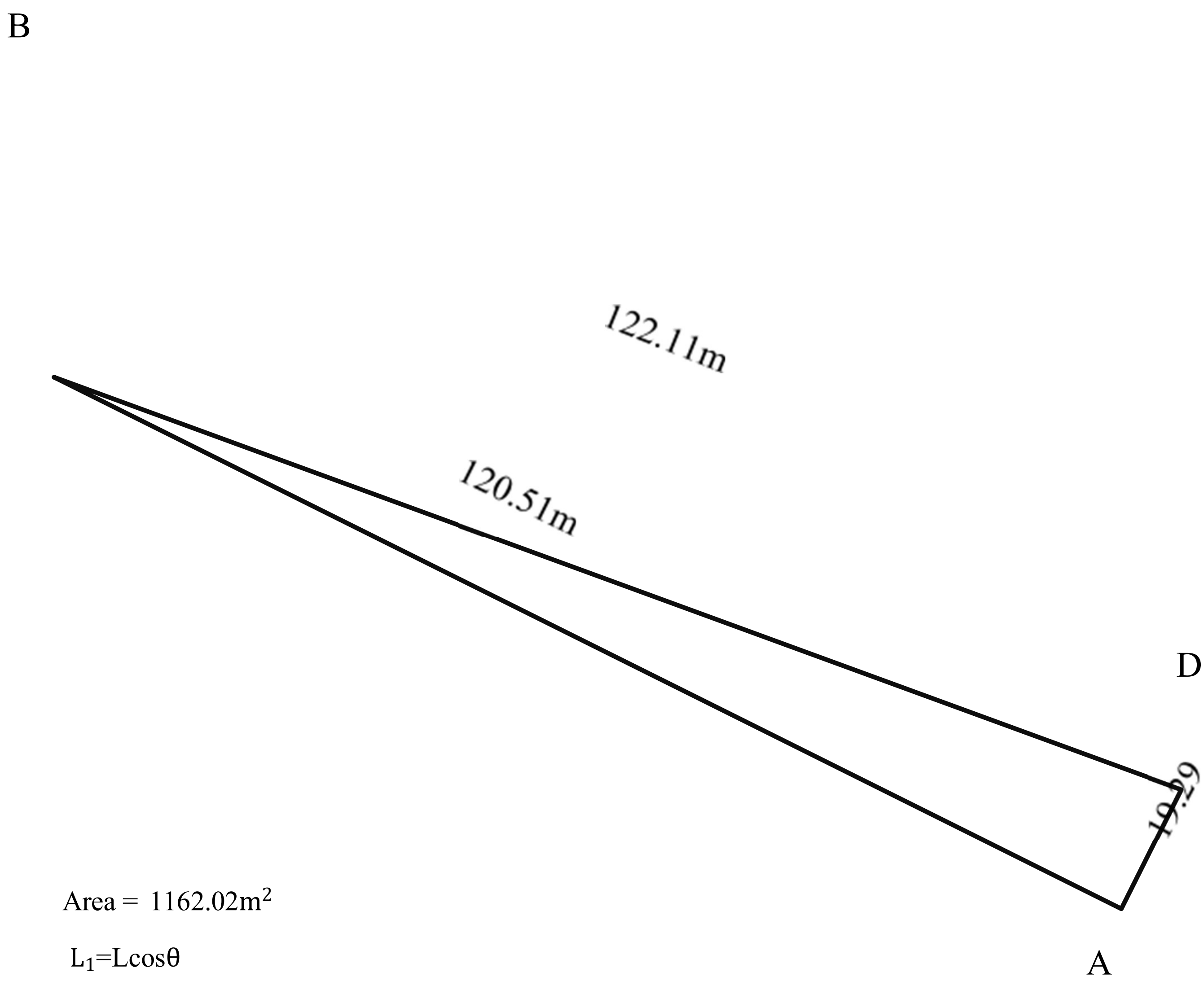
Disp(result_column);

The result of multiplying matrix A by B and C as a single column is:

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	-0.0009	0.0007	0	0	0	0
0	0	0	0.0021	0	-0.0001	0	0
0	0	0	0	0.0129	0.1979	0	0
0	0	0	-0.0001	0.0704	-1.0784	0	-0.0001
0	0	0	0	0	0	0	-0.0001
0	0	0	0	0	-0.0001	0	0.0001

0=	U1
0=	V1
-0.0001=	U2
0.000667=	V2
0.1054=	U3
-0.504=	V3
-0.00005=	U4
0=	V4

Triangle BCD WEEK 1		Triangle BCD WEEK 2		DISPLACEMENT
U1=	0	U1=	0.11725	0.058625
V1=	0	V1=	-0.44735	-0.223675
U2=	-0.0001	U2=	0	-0.00005
V2=	0.000667	V2=	0	0.000333333
U3=	0.1054	U3=	0	0.0527
V3=	-0.504	V3=	0	-0.252
U4=	-0.00005	U4=	0	-0.000025
V4=	0	V4=	0	0



Area = 1162.02m^2

L_1=Lcosθ

M_1=Lsinθ

L_1=122.11cos(280.4)

L_1=22.04

M_1=l22.11sin(280.4)

M_1=120.10

$$\begin{bmatrix} u_3 & v_3 & u_4 & v_4 \\ 485.76 & -2647.0 & -485.76 & 4699.41 \\ -2647.0 & 14424.01 & 2647.0 & -13202.01 \\ -485.76 & 2647.0 & 485.76 & -2647.0 \end{bmatrix} \times \frac{210 \times 1199.228}{122.11}$$

└ 2647.0 -14424.01 4699.41 13202.01 ┘ |

$L_2 = L \cos\theta$

$L_2 = 19.29\cos(199.64)$

$L_2 = -18.17$

$m_2 = L\sin\theta$

$m_2 = 19.29\sin(199.64)$

$m_2 = -6.48$

$$\begin{bmatrix} u_2 & v_2 & u_3 & v_3 \\ 330.15 & 117.74 & -330.15 & -117.74 \\ 117.74 & 41.99 & -117.74 & -41.99 \\ -330.15 & -117.74 & 330.15 & 330.15 \\ -117.74 & -41.99 & -117.74 & 41.99 \end{bmatrix} \times \frac{210\times 1162.02`1}{19.62}$$

$L_3 = L\cos\theta$

$L_3 = 120.51\cos(289.4)$

$L_3 = 40.03$

$m_3 = L\sin\theta$

$m_3 = 120.51\sin(289.4)$

$m_3 = -113.67$

$$\begin{bmatrix} u_3 & v_3 & u_4 & v_4 \\ 1602.40 & -4550.21 & -1602.40 & 4550.21 \\ -4550.21 & 12920.87 & -4550.21 & -1292087 \\ -1603.40 & 4550.21 & 1602.40 & -4550.21 \\ 4550.21 & -12920.87 & -4550.21 & 12920.87 \end{bmatrix} \times \frac{210 \times 1162.02`1}{120.51}$$

Global Matrix

u_1	v_1	u_2	v_2	u_3	v_3	u_4	v_4
485.76	- 264.7	485.76	264.7	0	0	0	0
- 264.7	14424.01	264.7	-14424.01	0	0	0	0
- 485.67	264.7	-873907.05	-1698282.937	- 330.15	-177.74	0	0
264.7	-14424.01	- 311657.78	605664.18	-117.74	- 41.99	0	0
0	0	- 330.15	-117.74	-188666.516	191063.32	-1602.40	4550.21
0	0	-117.74	- 41.99	4550.21	12920.87	4550.21	-12920.87
0	0	0	0	1602.40	4550.21	4550.21	-12920.87
0	0	0	0	12920.87	-14424.01	- 4550.21	12920.87

Define the 8x8 matrix A

A = [485.76, -2647, -485.76, 2647, 0, 0, 0, 0;

-2647, 14424.01, 2647, -14424.01, 0, 0, 0, 0;

-485.67, 2647, 873907.05, -1698282.937, -33095, -177.74, 0, 0;

2647, -14424.01, -311657.78, 605664.18, -117.74, -41.99, 0, 0;

0, 0, -330.15, -117.74, -188666.576, 191063.32, -1602.40, 4550.21;

0, 0, -117.74, -41.99, -4550.21, 12920.87, 4550.21, -12920.87;

0, 0, 0, 0, -1602.40, 4550.21, 4550.21, -12920.87;

0, 0, 0, 0, -4550.21, -12920.87, -4550.22, 12920.87];

Define the equation B and C

B = (210 * 1191.740 / 262.25)^-1; % Calculate B (Inverse of 210 * 1191.740 / 262.25)

C = (54.069 * 10^3); Calculate C

Multiply matrix A by B and C together

Result3 = A * B * C;   Matrix A multiplied by scalar B and C

Reshape the result to a single column vector

Result_column = result3(;

Display the results as a single column

Disp('The result of multiplying matrix A by B and C as a single column is:');

Disp(result_column);

The result of multiplying matrix A by B and C as a single column is:

-0.015 0	-0.0028	0.015		0	0	0	0
0.0817 0	0.015	-0.0817		0	0	0	0
0.015 0.1875	-4.9514	-9.6222	-	- 0.00 1	0	0	0
-0.0817 0.0007	-1.7658	-3.4316	-	- 0.000 2	0	0	0
0 1.069	-0.0019	-0.0007	-	1.082 5	-0.0091	0.0258	0.0258
0 0.0258	-0.0007	-0.0002	-	0.073 2	0.0258	-0.0732	-0.0732
0 0.0091	0	0	-	0.025 8	0.0258	-0.0732	-0.0732
0 0.0258	0	0	-	- 0.073 2	-0.0258	0.0732	0.0732

-0.00093=	U1
0.005=	V1
-2.94942=	U2
-1.056=	V2
0.007629=	U3
-0.01059=	V3

-0.02078=	U4
0.00432=	V4

	Triangle BDA Week 1		Triangle BDA week 2	Displacement
U1=	-0.000933333	U1=	-1.00885	-0.504891667
V1=	0.005	V1=	-0.1932	-0.0941
U2=	-2.94942	U2=	0	-1.47471
V2=	-1.056	V2=	0	-0.528
U3=	0.007628571	U3=	0	0.003814286
V3=	-0.010585714	V3=	0	-0.005292857
U4=	-0.02078	U4=	-0.43315	-0.226965
V4=	0.00432	V4=	-0.149475	-0.0725775

WEEK 2

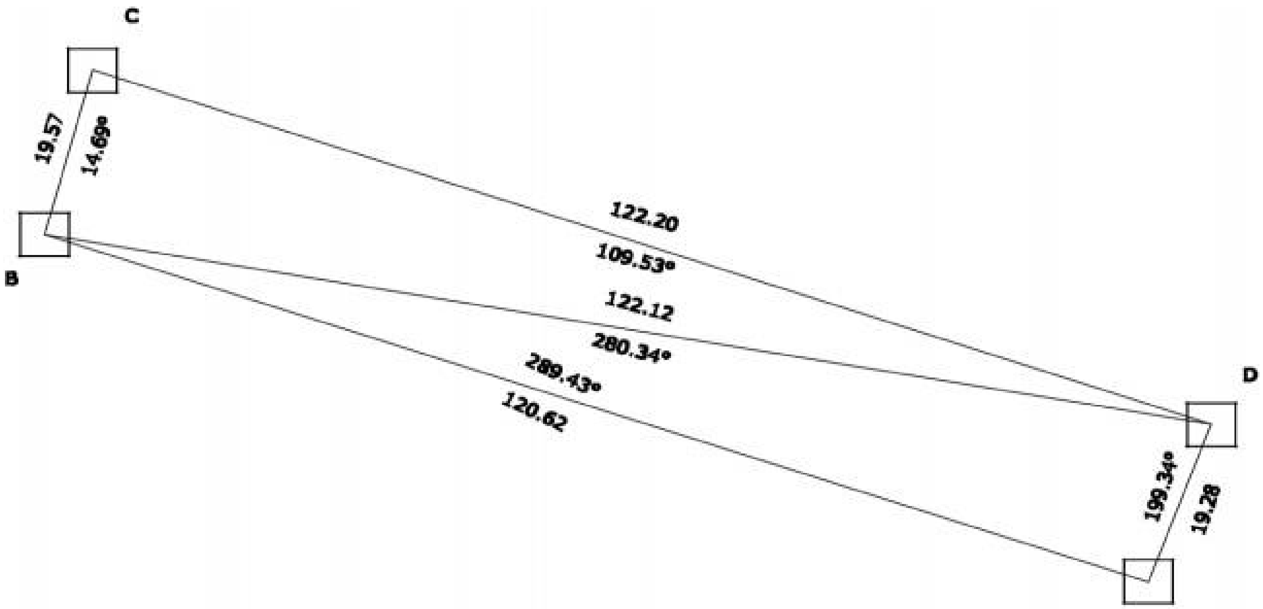
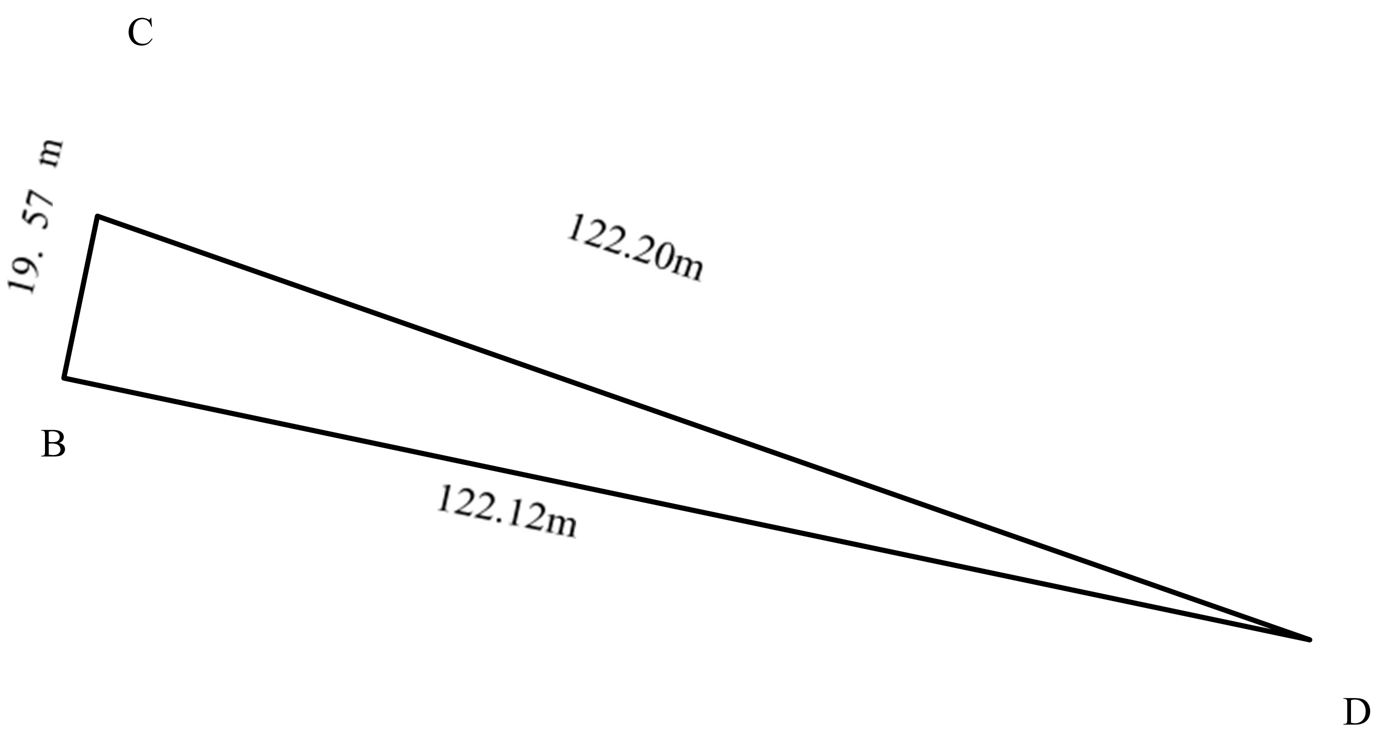


Figure 4.4 Showing the Distance and Bearing for data collected in week 2



Area= $1191.740m^2$

L_1=Lcosθ

M_1=Lsinθ

L_1=19.57cos(14.69)

L_1=18.93

M_1=l9.57sin(14.69)

M_1=4.96

$$K = \frac{EA}{L}\begin{bmatrix} l^2 & lm & -l^2 & -lm \\ lm & m^2 & -lm & -m^2 \\ -l^2 & -lm & l^2 & lm \\ -lm & -m^2 & lm & m^2 \end{bmatrix}$$

$$\begin{bmatrix} u_1 & v_1 & u_2 & v_2 \\ 358.34 & 93.89 & -358.34 & -93.89 \\ 93.89 & 24.60 & -93.89 & -1292087 \\ -358.34 & -93.89 & 358.34 & 93.89 \\ -93.89 & -24.60 & 93.89 & 24.60 \end{bmatrix} \times \frac{210 \times 1191.740}{19.57}$$

$L_2 = L \, CoS \, \theta$

$L_2 = 122.2COS\{109.53\}$

$L_2 = -40.85$

$m_2 = LSin \, \theta$

$m_2 = 121.20Sin\{109.53\}$

$m_2 = 115.17$

$$\begin{bmatrix} u_2 & v_2 & u_3 & v_3 \\ 1668.72 & -4704.69 & -1668.72 & 4704.69 \\ -4704.69 & 13264.13 & 4704.69 & -13264.13 \\ -1668.72 & 4704.69 & 1668.72 & -4704.69 \\ 4704.79 & -13264.13 & -4704.69 & 13264.13 \end{bmatrix} \times \frac{210 \times 1191.740}{122.20}$$

$L_3 = L \, CoS \, \theta$

$L_3 = 122.12COS\{280.84\}$

$L_3 = -22.97$

$m_3 = LSin \, \theta$

$m_3 = 122.12Sin\{280.84\}$

$m_3 = -119.94$

$$\begin{bmatrix} u_3 & v_3 & u_4 & v_4 \\ 527.62 & -2755.02 & -527.62 & 2755.02 \\ -2755.02 & 14385.60 & 2755.02 & -14385.60 \end{bmatrix} \times \frac{210 \times 1191.740}{\ldots}$$

				122.12
-527.62	2755.02	527.62	- 2755.02	
2755.02	-14385.60	- 2755.02	14385.60	

Global Matrix

u_1	v_1	u_2	v_2	u_3	v_3	u_4	v_4
358.34	93.89	- 358.34	93.89	0	0	0	0
93.89	24.60	- 93.89	- 24.60	0	0	0	0
- 358.34	- 93.89	-156676.12	115735.37	-1668.72	4704.69	0	0
- 93 89	- 24.60	- 441723.34	326297.60	4704.69	-13264.13	0	0
0	0	-1668.12	4704.69	2482288.54	36542943.43	- 527.62	2755.02
0	0	4704.69	-13264.13	12961515.04	190812468.5	2755.02	-14385.60
0	0	0	0	- 527.62	2755.02	2755.02	2755.02
0	0	0	0	2755.02	-14385.60	- 2755.02	14385.60

Define the 8x8 matrix A

A = [358.34 93.89 -358.34 -93.89 0 0 0 0; 93.89 24.60 -93.89 -24.60 0 0 0 0; -358.34 -93.89 -156676.12 115735.37 -1668.72 4704.69 0 0; -93.89 -24.60 -441723.34 326297.60 4704.69 -13264.13 0 0; 0 0 -1668.72 4704.69 2482288.54 36542943.43 -527.62 2755.02; 0 0 4704.69 -13264.13 12961515.04 190812468.5 2755.02 -14385.60; 0 0 0 0 -527.62 2755.02 2755.02 2755.02; 0 0 0 0 2755.02 -14385.60 -2755.02 14385.60];

Define the scalar values B and C

B = (210 * 1191.740/ 263.25); Calculate B

C = (54.069 * 10^3); Calculate C

Perform the calculation (A * B)^-1 * C

Result3 = inv(A * B) * C;

Reshape the result to a single column vector

Result_column = result3(

Display the result as a single column

Disp('The result of (A * B)^-1 * C as a single column is:');
Disp(result_column);

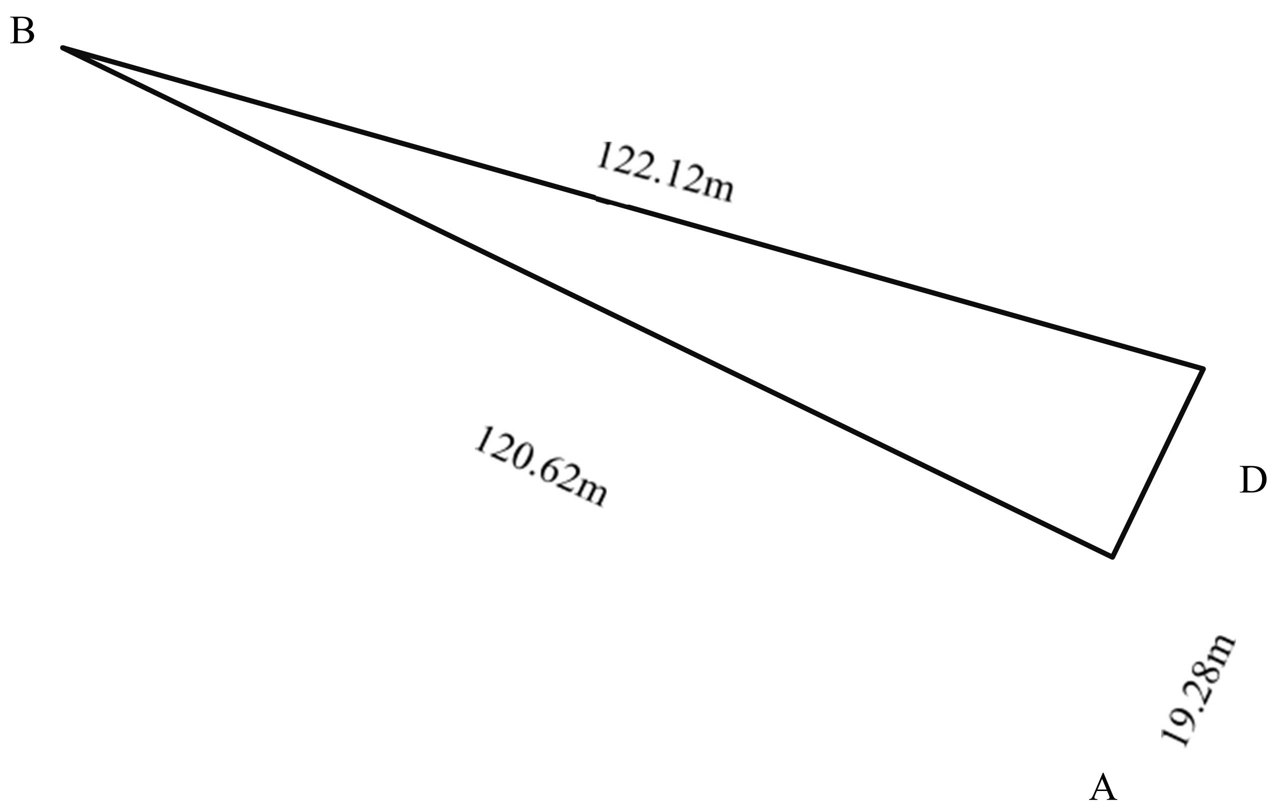
The result of (A * B)^-1 * C as a single column is:

-0.0832	0.3177	0	0	0	0	0	0	0.11725
0.3177	-1.2124	0	0	0	0	0	0	-0.44735
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

0.11725=	U1
-0.44735=	V1
0=	U2
0=	V2
0=	U3
0=	V3
0=	U4
0=	V4

Triangle BCD WEEK 1		Triangle BCD WEEK 2		DISPLACEMENT
U1=	0	U1=	0.11725	0.058625
V1=	0	V1=	-0.4473	-0.22367

			5	5
U2=	-0.0001	U2=	0	-0.00005
V2=	0.000667	V2=	0	0.000333333
U3=	0.1054	U3=	0	0.0527
V3=	-0.504	V3=	0	-0.252
U4=	-0.00005	U4=	0	-0.000025
V4=	0	V4=	0	0



Area = $1162.867m^2$

L_1=Lcosθ

M_1=Lsinθ

L_1=122.12cos(280.84)

L_1=22.97

M_1=l22.12sin(280.84)

M_1= -119.94

$$\begin{bmatrix} u_1 & v_1 & u_2 & v_2 \\ 527.62 & -2755.02 & -527.62 & 2755.02 \\ -2755.02 & 14385.60 & 2755.02 & -14385.60 \\ -527.62 & 2755.02 & 527.62 & -2755.02 \\ 2755.02 & -14385.60 & -2755.02 & 14385.60 \end{bmatrix} \times \frac{210 \times 1162.867}{122.12}$$

$L_2 = L\,CoS\,\theta$

$L_2 = 19.28COS\{199.34\}$

$L_2 = -18.19$

$m_2 = LSin\,\theta$

$m_2 = 19.28Sin\{199.34\}$

$m_2 = -6.39$

$$\begin{bmatrix} u_2 & v_2 & u_3 & v_3 \\ 330.88 & 116.23 & -330.88 & -116.23 \\ 116.23 & 40.83 & -116.23 & -40.83 \\ -330.88 & -116.23 & 330.88 & 116.23 \\ -116.23 & -40.83 & 11623 & 40.83 \end{bmatrix} \times \frac{210\times1162.867}{19.28}$$

$L_3 = L\,CoS\,\theta$

$L_3 = 122.12COS\{280.84\}$

$L_3 = 22.97$

$m_3 = LSin\,\theta$

$m_3 = 122.12Sin\{280.84\}$

$$\begin{bmatrix} u_3 & v_3 & u_4 & v_4 \\ 1609.61 & -4563.65 & -1609.61 & 4563.65 \\ -4563.65 & 12939.06 & 4563.65 & -12939.06 \\ -1609.61 & 4563.65 & 1609.61 & -4563.65 \\ 4563.65 & -12939.06 & -4563.65 & 12939.06 \end{bmatrix} \times \frac{210\times1162.867}{120.62}$$

\

Global Matrix

u_1	v_1	u_2	v_2	u_3	v_3	u_4	v_4
527.62	- 2755.02	- 527.62	2755.02	0	0	0	0
- 2755.02	14385.60	2755.02	-14385.60	0	0	0	0
- 527.62	- 2755.02	911581.02	-1672097.27	- 330.88	-116.2341	0	0
2755.02	-14385.60	- 320227.27	587364.05	-116.2341	- 40.83	0	0
0	0	- 330.88	-116.2341	-187091.57	186333.83	-1609.61	4563.65
0	0	-116.2341	- 40.83	- 530451.75	528301.82	4563.65	-12939.06
0	0	0	0	-1609.61	4563.65	4563.65	-12939.06
0	0	0	0	4563.65	-12939.06	- 4563.65	12939.06

Define the 8x8 matrix A

A = [527.62 -2755.02 -527.62 2755.02 0 0 0 0; -2755.02 14385.60 2755.02 -14385.60 0 0 0 0; -527.62 2755.02 911581.02 -1672097.27 -330.88 -116.2341 0 0; 2755.02 -14385.02 -320227.27 587364.05 -116.2341 -40.83 0 0; 0 0 -330.88 -116.2341 -187091.57 186333.83 -1609.61 4563.65; 0 0 -116.2341 -40.83 -530451.75 528301.82 4563.65 -12939.06; 0 0 0 0 -16091.61 4563.65 4563.65 -12939.06; 0 0 0 0 4563.65 -12939.06 -4563.65 12939.06];

Define the scalar values B and C

B = (210 * 1162.867/ 262.02); Calculate B

C = (54.069 * 10^3); Calculate C

Perform the calculation (A * B)^-1 * C

Result3 = inv(A * B) * C;

Reshape the result to a single column vector

Result_column = result3(;

Display the result as a single column

```
Disp('The result of (A * B)^-1 * C as a single column is:');
Disp(result_column);
```

The result of (A * B)^-1 * C as a single column is:

-1.6934	-0.3243	0	0	0	0	(	0
-0.3243	-0.0621	0	0	0	0	(	0
0	0	0	0	0	0	(	0
0	0	0	0	0	0	(	0
0	0	0	0	0	0	(	0
0	0	0	0	0	0	(	0
-2.8826	-0.5603	-0.0031	-0.0089	0.1231	-0.045	-0.0375	-0.0509
-1.0167	-0.1976	-0.0011	-0.0031	0.0434	-0.0159	0.0132	-0.018

-1.00885=	U1
-0.1932=	V1
0=	U2
0=	V2
0=	U3
0=	V3
-0.43315=	U4
-0.14948=	V4

	Triangle BAD Week 1		Triangle BAD week 2	Displacement
U1=	-0.000933333	U1 =	-1.00885	-0.504891667
V1=	0.00	V1	-0.193	-0.094

	5	=	2	1
U2=	-2.94942	U2 =	0	-1.47471
V2=	-1.056	V2 =	0	-0.528
U3=	0.007628571	U3 =	0	0.003814286
V3=	-0.010585714	V3 =	0	-0.005292857
U4=	-0.02078	U4 =	-0.43315	-0.226965
V4=	0.00432	V4 =	-0.149475	-0.0725775

CHAPTER FIVE

SUMMARY, RECOMMENDATIONS AND CONCLUSION

5.1. SUMMARY

This research project centered on implementing finite element analysis (FEA) as a tool for monitoring structural deformations in the University of Benin's Physics Department building. The investigation concentrated on assessing the building's structural soundness, pinpointing potential areas of vulnerability, and identifying deformations using finite element modeling techniques. The study emphasized the importance of leveraging sophisticated computational methods and numerical simulations to maintain the safety and longevity of essential infrastructure.

Through the combination of finite element analysis with routine monitoring and inspection protocols, the project facilitated preventive maintenance strategies while generating crucial information about the building's structural behavior. Additionally, the research sought to minimize the likelihood of structural deformations, enhance the building's long-term viability, and provide guidance for improving the effectiveness and efficiency of deformation monitoring procedures. These goals were accomplished through the development of a dependable monitoring framework and the implementation of strategic, preventive maintenance approaches.

5.2. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. Continuous structural monitoring should be implemented over extended periods, with appropriate attention given to the building's condition and performance.

2. State-of-the-art monitoring technologies should be adopted to enhance detection capabilities and data accuracy.

3. Long-Term Strategic Planning and Financial Investment: It is recommended that comprehensive long-term planning and investment strategies be developed for structural maintenance and renovation programs to ensure the sustained durability and service life of the Physics Department building.

5.3. CONCLUSIONS

The research concludes that implementing finite element analysis (FEA) for deformation monitoring of extensive surface structures, including the Physics Department building, has demonstrated both effectiveness and dependability. This investigation established that finite element modeling facilitates precise and accurate identification of structural deformations, with detection accuracy substantially enhanced through increased monitoring point density. The implemented FEA methodology not only enabled the recognition of deformation patterns but also established a thorough framework for examining structural modifications within a single observation period.

The research additionally uncovered significant insights regarding stress distribution throughout the structure, identifying regions experiencing different levels of deformation. Through examination of the displacement vector variance matrix, it became apparent that deformation patterns were non-uniform across the structure, with specific locations demonstrating more significant movements than others. This comprehensive understanding of deformation variability enables a more focused approach to structural evaluation and maintenance planning.

Furthermore, the results highlight the critical importance of ongoing monitoring utilizing finite element analysis, as it facilitates early identification of potential structural problems, thus allowing for prompt intervention before substantial damage develops. The incorporation of this sophisticated computational technique into regular monitoring protocols strengthens the durability and service life of vital infrastructure, protecting both occupants and property.

In summary, this study reinforces the value of finite element analysis as an essential instrument in contemporary deformation monitoring. Its capacity to deliver precision combined with comprehensive structural analysis makes it extremely valuable for ensuring the long-term stability, safety, and operational effectiveness of buildings and other large-scale structures.

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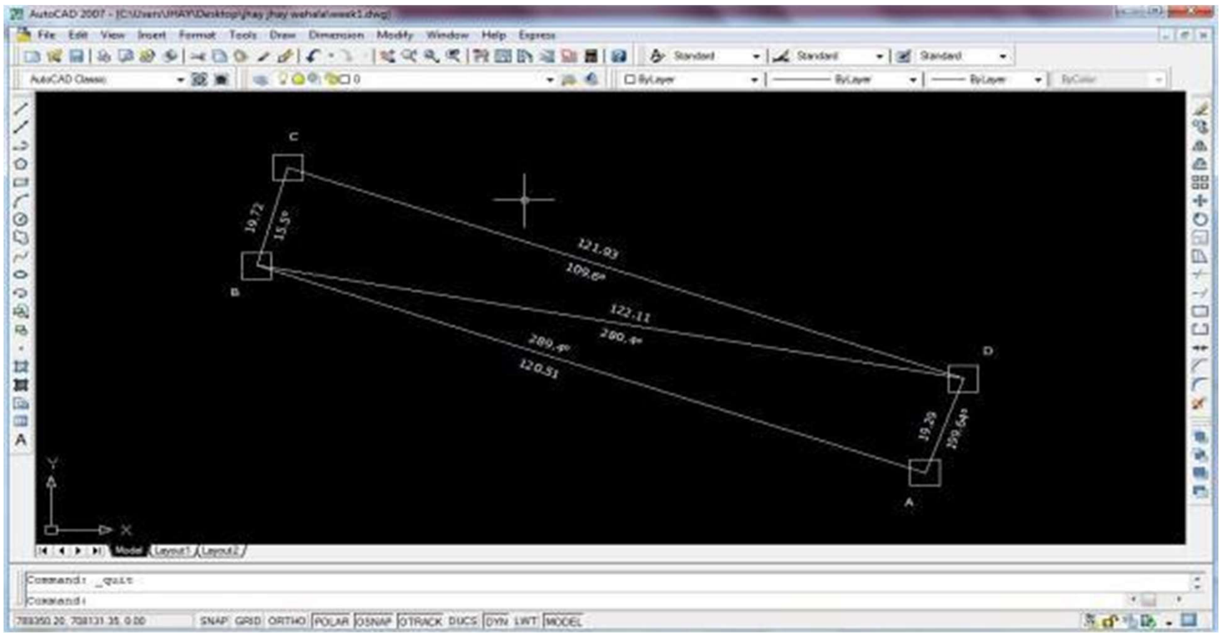
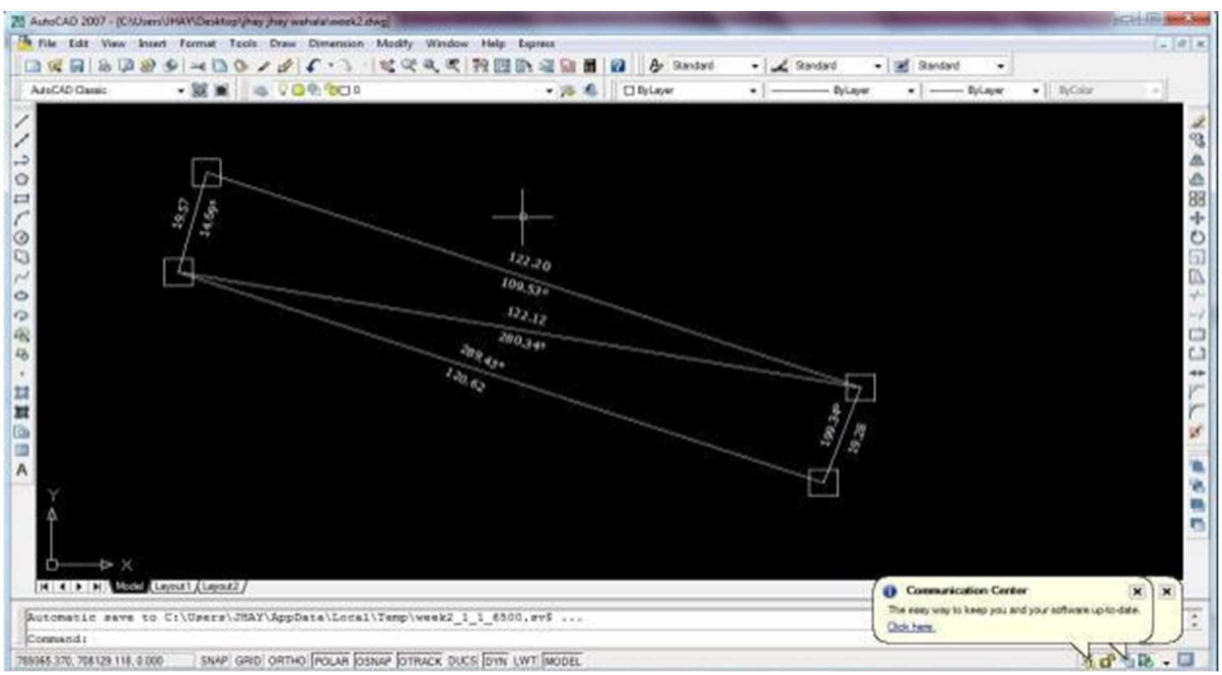
APPENDIX



C
19.72
15.5°
121.93
109.6°
B
122.11
280.4°
289.4°
120.51
D
19.29
199.64°
A
Command: _quit
Command:



19.57
14.6p°
122.20
109.53°
122.12
280.34°
289.43°
120.62
199.34°
19.28
Automatic save to C:\Users\JHAY\AppData\Local\Temp\week2_1_1_6500.sv$ ...
Command:
Communication Center

FIGURE A.1 Showing Autocad representation of the study area plotted with coordinates for week 1 and 2

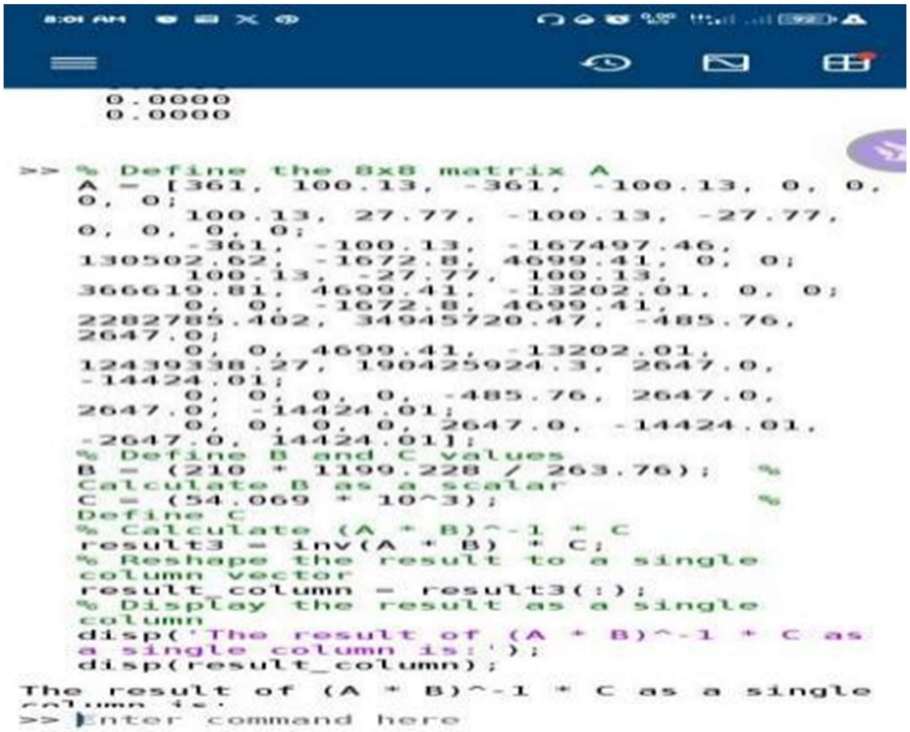


FIGURE A.2 Showing MATLAB Analysis for the Global Matrix, Stiffness Matrix and the

Force

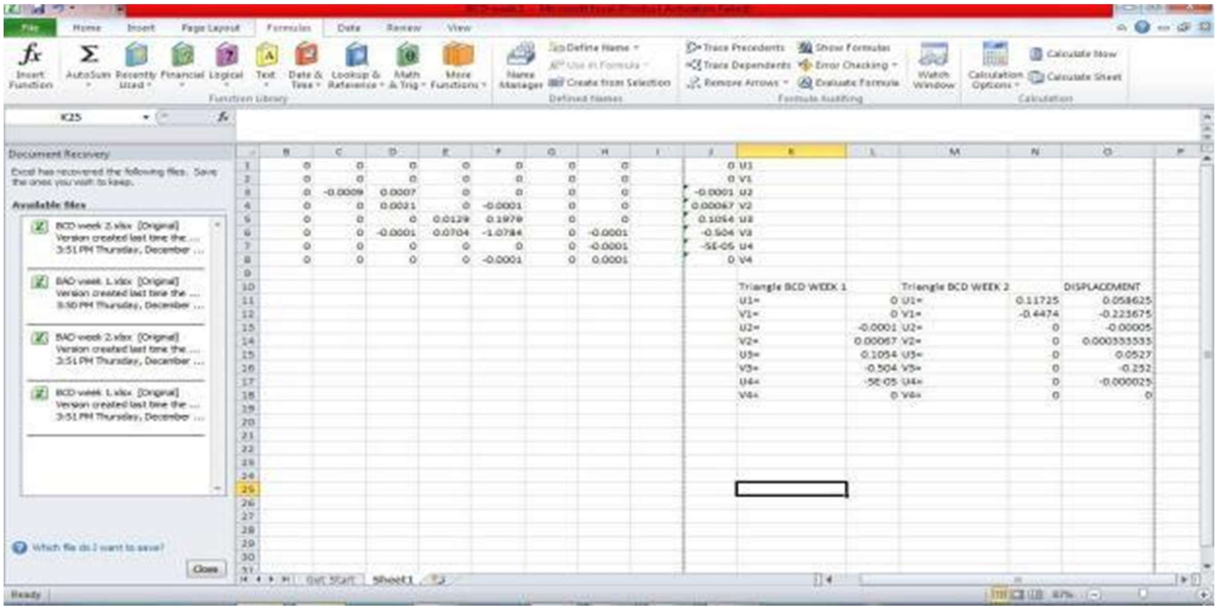


FIGURE A.3 Showing The Displacement Between week 1 and 2 for Triangle BCD

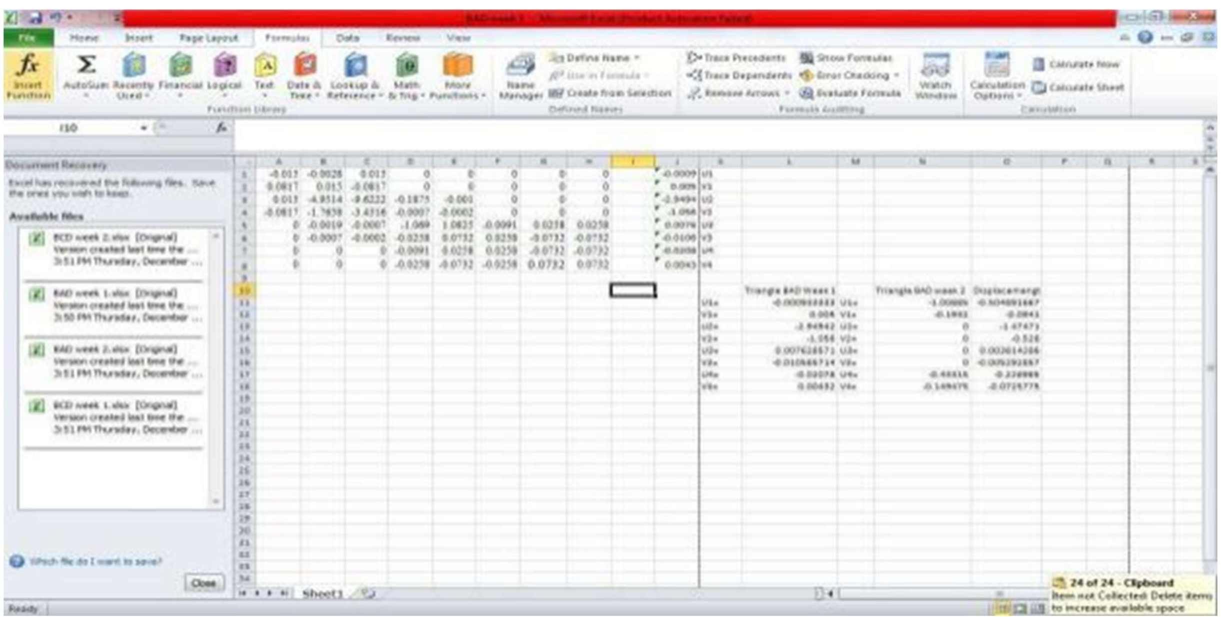


FIGURE A.4 Showing The Displacement Between Week 1 and 2 for Triangle BDA

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