ER Environmental Review Journal

Volume 11 No. 1, 2026.
ISSN:1118-7190

Research Article

STRUCTURAL DEFORMATION MONITORING SURVEY OF NNAMDI AZIKIWE UNIVERSITY MAIN LIBRARY, AWKA, ANAMBRA STATE.

Ebere Jude Ekemezie [1], Uzoma Chinenye Okeke[1]

[1] Department of Surveying and Geo-informatics, Nnamdi Azikiwe University Awka.

*Corresponding Author: Ebere Jude Ekemezie[1], E-mail: ej.ekemezie@unizik.edu.ng

Abstract

Deformation refers to the changes a deformable body undergoes in its shape, dimension and position. Deformation monitoring surveys constitute a systematic high-precision process of measuring and analyzing changes in position of natural or man-made features over a period of time to detect movement or displacement. Deformation monitoring surveys utilizes high-precision instrumentation such as geodetic GNSS receivers, total stations, laser scanners, digital micrometers, extensometers, and tilt sensors to observe, record, and interpret spatial changes to the millimeter. This enables the assessment of structural integrity and associated construction risks, and provide data for engineering analysis, construction management or early-warning systems. Nnamdi Azikiwe University main library is multi-story building whose foundation was designed to support very heavy gravity loads and to withstand the lateral forces imposed by winds and potential ground movements. But in view of the fact that a structural failure can lead to potential loss of life and property, it is very important to initiate and maintain a continuous deformation monitoring of this structure in order to ensure that it is exhibiting safe deformation behavior. Such monitoring provides us with the opportunity to identify anomalies that may signal unusual loading conditions or modified structural behavior, which can in the extreme case cause damage or catastrophic structural failure. To monitor this structure, second order geodetic reference stations were established on stable areas surrounding the building using GNSS receivers running on static mode. Deformation stations established on load bearing columns on the building were observed from the geodetic reference stations using static GNSS observation campaign in three epoch schemes spanning a period of 30months. After processing the field obtained data using post-processing software and precise orbit parameters, an analysis of the position coordinates across the baseline epoch and the final (third) epoch shows a minimum position difference of 0.0014m at DFN 2 and a maximum position difference of 0.0024 at DFN 4. Analysis of height difference across the same epoch shows a minimum height difference of 0.0016m at DFN 2 and 0.0032m at DFN4, which imply that the building was structurally stable within the observation session. Conclusively, it was recommended that although, the building under study lacked a monitoring scheme ab-initio, since this research has developed a schema, it is necessary that this monitoring be maintained so as to enable continuous modeling of its structural integrity.

Keywords: GNSS; GNSS Receivers; Deformation; Structural Integrity; Static GNSS Observation.

Article History: Received: June 10, 2026 Accepted: June 18, 2026 Published: July 21, 2026

1. Introduction

Deformation monitoring surveys is the systematic measurement and tracking of the spatial alteration in the shape or dimensions of an object because of stresses induced by applied loads over time. This type of survey is becoming ever more critical, as the stability of ageing infrastructures are at stake. Structures (such as dams, single or long span bridges, high rise buildings, reservoirs, sport domes, stadium, tunnel, viaducts, industrial complexes, etc.) are subject to deformation due to factors such as changes of ground water level, soil mass, temperature changes, tidal phenomena, tectonic movements, land movements, or any other natural disasters. Therefore, it is important to measure this movement for the purpose of ensuring that structural integrity and public safety is not compromised (U.S. Army Corps of Engineers [USACE], 2018)

There are several techniques for measuring deformations. These can be grouped mainly into two namely: geodetic and non-geodetic techniques (Kalkan et al., 2010). Each measurement technique has its own advantages and drawbacks. Geodetic techniques, through a network of points interconnected by angle and/or distance measurements, usually supply a sufficient redundancy of observations for the statistical evaluation of their quality and for detection of errors. They give global information on the behavior of the deformable structure with respect to some reference points that are assumed to be stable while the non-geodetic techniques give localized and locally disturbed information without any check unless compared with some other independent measurements. However, the instruments used in non-geodetic measurements have the advantage of being easier to adapt for automatic and continuous monitoring than conventional instruments of geodetic measurements. In addition, conventional geodetic survey has the problem of being labor intensive and requires skillful observers, while geotechnical instruments, once installed, require only infrequent checks on their performance (USACE, 2018).

The deformation measurement technique to be adopted for a particular project which could be geodetic or non-geodetic, is determined considering the type of the structure on which deformations will be monitored, its environmental conditions and expected accuracy from the measurements. Geodetic deformation measurement techniques include conventional surveys (such as precise trigonometric or differential leveling measurements, angle and distance measurements (which provides localized horizontal and vertical displacement monitoring by tracking prisms installed on the structure), etc.), photogrammetric surveys (terrestrial, aerial and digital photogrammetry), satellite surveys (such as GPS, GLONASS, BeiDou and GALILEO receivers), and some special techniques (such as interferometry SAR Images, digital and hydrostatic leveling, alignment surveys, Terrestrial Laser Scanner technique (generates dense point clouds to detect millimeter-level surface deformations and structural buckling without the need to physically access the structure)).

Non-geodetic (geotechnical/structural) measurements include using crack meters, reversed pendulums, tilt meters (provide real-time measurement of angular rotation or inclination in structural components e.g., columns or piers), strain meters (bonded to or embedded in materials (like steel or concrete) to directly measure localized expansion or compression forces), extensometers (measures displacement/separation between two points, commonly used to monitor crack propagation or foundation settlement.), piezometer (measures pore water pressure, which heavily dictates internal stress and potential structural deformation in earth structures), joint-meters, plumb lines, micrometers, settlement column, inclinometers (USACE, 2018).

2. Literature Review

Given that deformation monitoring is an important procedure used for evaluating structural health (Detchev et al., 2011), there have been several empirical research efforts made in this field of study. For instance, Wipf et al. (2011) carried out comprehensive research involving Bridge 0309 at the Northeast Junction of I-80/I-235/I-35 Interchange in Des Moines, Iowa using combined GNSS and Total Station technologies. Wipf et al. (2011) concluded that GNSS is a viable alternative to conventional forms of bridge movement

monitoring. The ability to collect precise positioning data without near ground-based benchmarks and during all types of weather conditions—and to remotely operate and analyze the GNSS equipment in real-time—make this technology worth investigating further.

Kalkan et al. (2010), carried out a structural deformation monitoring of Ataturk dam in Turkey using a combination of high precision theodolites, EDM instruments, dual frequency GNSS receivers and high precision digital level instruments. Kalkan et al. (2010) conducted a mock static GNSS surveying on 55 different points of the dam embankment for testing whether GNSS method can be used for the deformation monitoring exercise. As a result of desirable outcomes obtained, Kalkan et al. (2010) deployed GNSS observation campaign for nearly all points on the dam embankment.

Erol et al. (2004), investigated the deformation of Karasu viaduct (bridge) using GNSS and precise differential leveling data. Karasu viaduct is 2.16km in length and is located in the west of Istanbul, Turkey. The viaduct consists of two separate railway tracks constructed on 110 piers (each track has 55 piers). There is a 40-meter width between the two piers and one deformation point is constructed within every 5 piers sequence. The deformation measurements of Karasu involved four measurement campaigns. Erol et al. (2004) noted at the end of the research that no significant changes in the horizontal and vertical positions of the deformation points on the viaduct were noted. However, it was surprising to find that two points that had been chosen as reference points were deformed both horizontally and vertically. After geological and geophysical investigations on this two reference points, the reason why they deformed was captured. According to the report, because the area where these two reference points were located is marshy and the foundation of the constructions of these two reference points are not founded as deep as the piers of the viaduct, they were easily deformed as a result of external unfavorable environmental conditions.

Wan-Aziz et al. (2005) performed a deformation study of Sarawak Business Tower which is located at Stulang Laut, Johor Bahru, Malaysia. The building's structure consists of 30-storey tower mostly housing commercial offices. The reference network used for this research consists of three GNSS controls located on stable areas near the structure. From this reference network, the one and only deformation point located on the top of Sarawak Business Tower was surveyed in a three-day campaign using Leica System 500 GNSS receivers operating with a 1 second sampling rate. After adjusting the field obtained data, Wan-Aziz et al. (2005) concluded that the building is stable in three dimensions. Nevertheless, the fact that the duration of the observation campaign is very short makes it difficult to rely on such data for the determination of the structural integrity of the building. In short term monitoring (3-days), Noise as a result of human traffic loading and unloading of the structure (elastic deformation) can be misinterpreted as permanent (plastic) deformation of the structure. On the other hand, it is noteworthy to say that short term observations can detect permanent (plastic) deformation if the short-term variance of the structure's motion is extremely high. Another challenge that Wan-Aziz et al. (2005) had, was using only one deformation monitoring point located on one edge of the high-rise building rooftop to model the entire structural behavior of the building. This idea based on the assumption that all parts of the building is experiencing uniform deformation behavior may not be universally true at all times.

Abdullahi and Yelwa (2016) executed a structural deformation monitoring survey of new administrative building of Federal school of surveying in Oyo, Nigeria for the purpose determining whether the structure is still stable in three dimensions. The reference geodetic network used for the research consists of eight geodetic controls located on areas near the structure. From this reference network, thirteen deformation points located on the building was surveyed in three different epochs. Given that the reference network used in the deformation monitoring exercise was too close ($\leq 30m$) to the building under study and are deemed to be within the pressure zone of the building. It was observed that there is a high probability that the building under study, the reference network and the deformation network will experience similar or near similar horizontal and vertical movements which will make the net motion of the deformation points to be difficult to notice.

Although several studies have been previously conducted to study horizontal and vertical structural deformation in different parts of the world, it should be noted that this topic is far from being exhausted as a research area because different structures exhibit different deformation behavior and as such, one cannot deduce the amount of expected deformation of a structure using data collected from other structures. Therefore, it becomes important to compute any structure's displacements down to the millimeter level to prevent disasters, guide maintenance, and manage structural risks caused by applied loads, soil settlement and environmental stress.

2.1 Research Aim and Objectives

Aim: To conduct a three-dimensional structural stability monitoring of Nnamdi Azikiwe University main library (Prof Festus Nwakor Library) using multi-epoch GNSS observation in order to determine whether it is exhibiting safe or unsafe structural behavior.

Research Objectives: The aim of this research was achieved through the following specific objectives;

a) To establish second order three-dimensional geodetic reference network on stable areas surrounding the structure using static GNSS observation technique.
b) To establish deformation points on critical areas on the building for the monitoring exercise.
c) To observe the deformation points from the geodetic reference network in three epochs and to process and analyze the resulting field data which will serve as baseline information for determining if the building is still stable in three dimensions or whether the variance of its movements is too high.

3.0 Study Area, Research Description and Methods

3.1 Study Area

Prof Festus Aghagbo Nwakor Library is located within the premises of Nnamdi Azikiwe University main campus Awka. The library is positioned approximately at the middle of the university compound; it is bounded in front by the school of Postgraduate Studies Building, on the sides by Law Faculty, Female hostels, Faculty of Management Sciences, Science Village, Faculty of Engineering and undeveloped spaces. Nnamdi Azikiwe Central library is a multistory building, it is expected that the library will be visited by its student's population of about 40,000 persons (Unizik, 2026). The Staff strength of the library is over 100 active-duty employees comprising of professional staff, para-professionals and general duty staff. From the

data above, it is easily seen that the building is in constant stress and strain ensuing from gravitational loads (self-weight of structure, weight of books, furniture, people, etc.) as a result of loading and unloading conditions. The library service is structured according to the various library operations that currently exist in the library system. These departments/units include acquisition, cataloging, circulation, reference services, serials, digital library and institutional repository (Anyaegbu et al., 2015).

3.1.1 Research Description and Methods

The foundation of Nnamdi Azikiwe University main library was designed to support very heavy gravity loads and to withstand the lateral forces imposed by winds and potential ground movements. But in view of the fact that a structural failure can lead to potential loss of life and property, it is very important to initiate and maintain a continuous deformation monitoring of this structure as such monitoring provides us with the opportunity to identify anomalies that may signal unusual loading conditions or modified structural behavior, which can in the extreme case cause damage or catastrophic structural failure.

The importance of deformation monitoring studies can never be overemphasized. There have been different scenarios of structural failures all over the world. Examples of these failures include: The collapse of Brazilian dam in the Southeastern State of Minas Gerais (Grinberg & Reverdosa, 2019); the Nanfang'ao Arch bridge collapse in Northeastern Taiwan (AP, 2019); the Majerhat bridge collapse in Kolkata, India (BBC, 2018); the frequent collapse of buildings in Lagos State and other States in Nigeria (Coren, 2025); the Genoa Morandi Bridge collapse in Italy (Butler, 2018); the Cancura bridge collapse near Puerto Octay, Chile (Bnamericas, 2018). All these could have been averted if there had been a program for monitoring the stability or deformation of these structures.

To monitor the structural integrity of the university library, a geodetic approach to deformation monitoring was employed. Second order geodetic reference stations were established on stable areas surrounding the structure, also, through the help of a geo-technical expert and a structural engineer, second order geodetic deformation stations were established on critical points on the building. The deformation points consist of four stations (DFN 1, DFN2, DFN 3 and DFN 4) located close to load bearing columns and on other points on the building where any three-dimensional strain can easily be noticed (see fig. 2). The geodetic reference network consists of three stations (RFN 1, RFN 2 and RFN 3) arranged in triangular geometry, such that the deformation points are embodied within the framework of this triangle (see fig. 1). The geodetic deformation monitoring stations are in the form of bolts drilled and cast in-situ into the main load bearing columns of the monitored building. The essence of placing the deformation monitoring studs on these columns is to ensure that even small strain on the building which is transmitted to these columns are easily noticed as deformation on these studs.

The three-dimensional coordinates of the geodetic reference points namely RFN1, RFN2 and RFN3 was determined by static GNSS surveying method using Hi-target V500 receiver. This is because static GNSS observation gives the most refined accuracy possible in the most demanding GNSS surveying campaign. The Surveyors Council of Nigeria (SURCON) has published a document titled "Specifications for Geodetic

Surveys in Nigeria". This document specifies not only orders of accuracy for national horizontal and vertical control surveys but also provide guidelines on instruments, field and office procedures to follow in other to achieve these orders of accuracy. The second order horizontal and vertical control survey of reference geodetic network and geodetic deformation network by static GNSS observation was designed following the specifications set forth by the aforementioned manual. The manual's guidelines in designing the geometry of the network, in instrumentation, in calibration procedures, in observation techniques, in office computation and analysis procedures was adhered strictly to (Surcon, 2003). During field observation, GNSS satellites continually transmit signals, but if these were continuously collected by the receivers, the volume of data and hence the storage requirements would become overwhelming. Thus, the receivers are set to collect samples of the data at a certain time interval, which is called epoch rate (Ghilani and Wolf, 2012). The value for the epoch rate used for data collection was 1sec while the elevation mask/cut off angle was set at 10degrees for both the field observation of reference and deformation monitoring networks.

During post-processing of the reference network using Bernese GNSS postprocessing software (version 5.2), 6 hours base station data collected by IGS CORS stations (FUNC Portugal, LPAL Spain, MAL2 Kenya, MAT1 Italy, MBAR Uganda, NKLG Gabon, SFER Spain, STHL United Kingdom, TDOU South Africa, VILL Spain, YEBE Spain and ZAMB Zambia) was injected in order to produce a robust network with global accuracy. The coordinates of the four geodetic deformation monitoring stations namely DFN1, DFN2, DFN3 and DFN4 was also determined by static GNSS surveying using Hi-target V500 receiver in three data collection epochs using RFN1, RFN2 and RFN3 as a three-dimensional fixed reference (fixed in horizontal and vertical), while employing geo-solution post-processing software.



Fig. 1: Left: Spatial Distribution of Reference Geodetic and Geodetic Deformation Monitoring Stations. (NOTE: Red lines shows reference geodetic network, green lines show deformation monitoring network while black lines show structure under monitoring. Not to Scale), Right: GNSS receiver on a deformation monitoring stud.

The final adjusted coordinates of the geodetic monitoring stations (DFN 1, DFN 2, DFN 3 and DFN 4) are listed in table 1.0 for all three epochs of observation. The adjustment process used for driving final station coordinates is weighted least-squares algorithms. Phase preprocessing is undertaken in a baseline-by-baseline mode using triple-differences. In most cases, cycle slips are fixed by the simultaneous analysis of different linear combinations of L1 and L2. If a cycle slip cannot be fixed reliably, bad data points are removed or new ambiguities are set up, a data screening step on the basis of weighted post-fit residuals is also performed, and outliers are removed. IGS14 station coordinates and velocities are mapped to the mean epoch of observation. All coordinates are based on the IGS realization of the ITRF2014 reference frame. Geoid-ellipsoidal separations, in this campaign, are computed using a spherical harmonic synthesis of the global EGM2008 geoid. Earth Gravitational Model EGM2008 released by the National Geospatial-Intelligence Agency (NGA) EGM Development Team is used to compute above-geoid heights. This gravitational model is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159. Zenith delay corrections are estimated relying on the WETGMF mapping function. First-order ionospheric effect was eliminated by forming the ionosphere-free linear combination of L1 and L2. Zenith delay parameters and pairs of horizontal delay gradient parameters are estimated for each station.

Geodetic monitoring strictly measures movement relative to designated reference points, this creates a condition known as “moving baseline problem”, in which if the reference and deformation network are located close in space, within the pressure zone of the structure under observation, this will result in a situation in which the reference network and the deformation network will experience similar or near similar horizontal and vertical motions which will make the net motion of the deformation points to be difficult to notice as experienced in the work of Abdullahi and Yelwa (2016). To prevent this scenario from playing out, the reference geodetic network was located 0.8km -1km away from the possible deformation zone of the structure.

An ionospheric map derived from the contributing reference stations is used to aid ambiguity resolution. Ambiguities are resolved in a baseline-by-baseline mode using the Code-Based strategy for 180-6000km baselines, the Phase-Based L5/L3 strategy for 18-200km baselines, the Quasi-Ionosphere-Free (QIF) strategy for 18-2000km baselines and the Direct L1/L2 strategy for 0-20km baselines. The adjustment process used for driving final station coordinates is weighted least-squares algorithms. Coordinate constraints are applied at the reference sites with standard deviation of 1mm and 2mm for horizontal and vertical components respectively. Satellite center of mass correction and phase center calibration was done by applying IGS14 phase-center variation model. Coordinate uncertainty is expressed in terms of the 95% confidence level for ITRF2014. Position and height uncertainties are scaled using an empirically derived model which is a function of data span, quality and geographical location.

Table 1.0: Geodetic Monitoring Network Coordinates and epoch differences

Epoch 1 (Position and Height: 95% C.L.) (Coordinate System: UTM WGS84 ZONE 32N)				**Difference in Position and Height between Epochs (Epoch 1 to 2)**	
Point ID	**North (m)**	**East (m)**	**Height (m)**	**∆Position**	**∆Height**

DFN 1	691055.6281	291513.5934	88.1720	0.0012	-0.0015
DFN 2	691011.4379	291468.6914	88.2500	0.0011	0.0014
DFN 3	691034.7527	291446.2951	88.1905	0.0014	-0.0017
DFN 4	691085.4458	291484.1794	88.1635	0.0017	0.0021
Epoch 2 (Position and Height: 95% C.L.) (Coordinate System: UTM WGS84 ZONE 32N)				**Difference in Position and Height between Epochs (Epoch 2 to 3)**	
				ΔPosition	**ΔHeight**
DFN 1	691055.6293	291513.5934	88.1705	0.0019	0.0033
DFN 2	691011.4374	291468.6924	88.2514	0.0010	0.0002
DFN 3	691034.7540	291446.2947	88.1888	0.0026	0.0036
DFN 4	691085.4475	291484.1790	88.1656	0.0023	0.0011
Epoch 3 (Position and Height: 95% C.L.) (Coordinate System: UTM WGS84 ZONE 32N)				**Difference in Position and Height between Epochs (Epoch 1 to 3)**	
				ΔPosition	**ΔHeight**
DFN 1	691055.6283	291513.5918	88.1738	0.0016	0.0018
DFN 2	691011.4383	291468.6927	88.2516	0.0014	0.0016
DFN 3	691034.7533	291446.2972	88.1924	0.0022	0.0019
DFN 4	691085.4473	291484.1813	88.1667	0.0024	0.0032



Fig. 2: Spatial Distribution of Geodetic Deformation Monitoring Stations on Library building main columns shown by red arrow.

4.0 Results and discussion

A close observation of table 1.0, across the three epoch of survey campaigns shows that there is negligible (mm) change in the three-dimensional coordinates of the deformation studs for the time interval between 15/06/2023—16/12/2025 (which roughly translates to a time period of approximately 30months) and as such the building is deemed stable both horizontally and vertically for the aforementioned period of time. An analysis of the position coordinates across the baseline epoch and the final (third) epoch shows a minimum position difference of 0.0014m at DFN 2 and a maximum position difference of 0.0024m at DFN 4. Analysis of height difference across the same epoch shows a minimum height difference of 0.0016m at DFN 2 and 0.0032m at DFN4.

5.0 Conclusion

Structural deformations monitoring involves evaluating changes in a structure's shape or dimensions as a result of applied internal or external stress. Geodetic deformation monitoring methods measure absolute or relative three-dimensional displacements by comparing coordinates of specific target points against a stable external reference network over multiple epochs. Geodetic deformation monitoring methods provide the "big picture" of a structure's movement, while non-geodetic methods provide targeted, high-frequency physical data about structural stresses and localized cracking.

Relying solely on a geodetic only approach (like GNSS) for deformation monitoring poses distinct limitations. While these methods excel at providing exact 3D coordinates, a geodetic-only approach measure only surface displacement. They cannot detect internal or sub-surface deformations (e.g., internal fracturing of an underlying bedrock, or sub-surface slippage). Moreover, knowing that a structure is moving is different from knowing why. Geodetic-only systems do not gather data on external loading and offloading (temperature, water levels, structure traffic). As such, without integrated geotechnical or environmental sensors, it is difficult to determine if a movement is elastic (reversible structural deformation) as seen on DFN 1 and DFN 3 in epoch 2 to 3 or plastic (permanent structural failure).

Another issue with geodetic only approach to deformation is latency and temporal gaps. To minimize operational costs, terrestrial surveying is often done on discrete epochs rather than continuously and as such fast-moving events like sudden slope failures, seismic tremors, or structural vibrations can be missed between survey intervals. In addition, since geodetic monitoring strictly measures movement relative to designated reference points, this creates a condition known as “moving baseline problem”. If the designated reference points themselves shift due to ground settling or tectonic activity, the entire deformation model becomes skewed, leading to false alarms or missed structural threats.

Furthermore, as structural stability assessment surveys may be required through the entire life cycle of a project which may span into decades, it is necessary that during the early planning phases of a project that

a comprehensive monitoring plan consisting of reference points and deformation points should be permanently monumented in area that are conducive for periodic monitoring of surveys rather than making the monument post-construction as can be seen in the case of Prof Nwakor Library.

Conclusively, to mitigate deformation measurement blind spots, modern structural health and geotechnical monitoring relies on data fusion approach. By integrating geodetic networks with geotechnical instrumentation, engineers can combine surface measurements with sub-surface data to create a comprehensive, continuous robust structural health monitoring safety system.

References

Abdullahi, I. M., & Yelwa, N. A. (2016). Structural Deformation Monitoring Surveys of New Administrative Building of Federal School of Surveying, Oyo – Nigeria. International Journal of Science and Technology, Volume 6 (1).

Anyaegbu, M. I., Obiozor-Ekeze, R. N & Aghauche, E.E. (2015). Motivation Strategies for Enhanced Library Services in Prof. Festus Aghagbo Nwakor Library. International Institute for Science, Technology and Education, Volume 41, 79-86.

AP, (2019, October 3). Possible Structural Issues Examined in Taiwan Bridge Fall. Associated Press News. https://apnews.com/a259b35ac4d1470fa9e71f1f649c7ef4

BBC, (2018, September 4). People Feared Trapped after India Bridge Collapse. British Broadcasting Corporation. https://www.bbc.com/news/world-asia-india-45411341

Bnamericas, (2018, June 25). Chile Opens Probe into Deadly Bridge Collapse. Business News Americas. https://www.bnamericas.com/en/news/chile-opens-probe-into-deadly-bridge-collapse

Butler, N. (2018, August 16). Genoa Bridge Collapse: Hundreds Ordered to Evacuate**.** ***Aljazeera*****.** https://www.aljazeera.com/video/2018/8/16/genoa-bridge-collapse-hundreds-ordered-to-evacuate

COREN, (2025, August 8). Building Collapse Record in 2025 in Nigeria as at 8th August, 2025. Council for the Regulation of Engineering in Nigeria. https://coren.gov.ng/building-collapse-record/

Detchev, I., Habib, A., & El-Badry, M., (2011, May 1-5). Case Study of Beam Deformation Monitoring using Conventional Close-Range Photogrammetry. American Society for Photogrammetry and Remote Sensing (ASPRS) 2011 Annual Conference, Milwaukee, Wisconsin. http://www.asprs.org/a/publications/proceedings/Milwaukee2011/files/Detchev.pdf

Erol, S., Erol, B. & Ayan, T., (2004, July 12-23). A General Review of the Deformation Monitoring Techniques and a Case Study: Analyzing Deformations using GPS/Leveling. International Society for Photogrammetry and Remote Sensing (ISPRS) XXth ISPRS Congress Technical Commission VII, Istanbul, Turkey. http://www.isprs.org/proceedings/XXXV/congress/comm7/papers/123.pdf

Ghilani, D. C., & Wolf, P.R. (2012). Elementary Surveying—An Introduction to Geomatics (13th Ed.). Pearson.

Grinberg, E., & Reverdosa M. (2019, February 1). Death toll rises in Brazil Dam Collapse as Mining Company Faces Criticism. Cable News Network. https://amp.cnn.com/cnn/2019/01/27/americas/brazil-dam-collapse/index.html

Kalkan, Y., Alkan, R. M. & Bilgi, S., (2010, April 11-16). Deformation Monitoring Studies at Ataturk Dam. International Federation of Surveyors (FIG) Congress 2010 Facing the Challenges – Building the Capacity, Sydney, Australia. http://www.fig.net/resources/proceedings/fig_proceedings/fig2010/papers/fs01d/fs01d_kalkan_alkan_et_al_4466.pdf

SURCON, (2003). Specifications for Geodetic Surveys in Nigeria (1st Ed.). Surveyors' Council of Nigeria.

Unizik, (2026, January 29). Why Unizik. Nnamdi Azikiwe University. https://unizik.edu.ng/about/why-unizik/

U.S. Army Corps of Engineers [USACE], (2018, February 1). Engineering Design Manual-(EM 1110-2-1009) Structural Deformation Surveying. U.S. Department of the Army. https://www.publications.usace.army.mil/portals/76/publications/engineermanuals/em_1110-2-1009.pdf

Wan-Aziz, W.A., Zulkarnaini, M. A & Shu, K. K., (2005, April 16-21). The Deformation Study of High Building using RTK-GPS: A First Experience in Malaysia. International Federation of Surveyors (FIG) Working Week 2005 and GSDI-8-From Pharaohs to Geoinformatics, Cairo, Egypt. https://www.fig.net/resources/proceedings/fig_proceedings/cairo/papers/ts_43/ts43_01_wanaziz_etal.pdf

Wipf, T.J., Phares, B.M & Greimann, L., (2011, December). Evaluation of Bridge Movement Measurement using GPS. Iowa State University-Institute for Transportation (InTrans)-Bridge Engineering Center (BEC). https://bec.iastate.edu/wp-content/uploads/2018/03/gps_bridge_mvmt_msrmt_t2.pdf