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Establishment of Baseline Data for Monitoring of Deformation of Murtala Mohammed Bridge (MMB) Lokoja Kogi State, using GPS

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ABSTRACT

Deformation is the change in shape, size and/or figure of an object from its normal to an abnormal state as a result of forces acting on, under or near the object. Deformation has been known to occur in areas where previous mining activities and dredging have taken place and areas where large amount of ground water has been withdrawn. This paper is focused on the establishment of baseline data where the periodic monitoring of the Murtala Mohammed Bridge (MMB) can be based as the Niger river dredging project was about to commence. Points were established on and near the bridge and were coordinated from first order triangulation points. The technique of differential GPS was employed in establishing these baseline data. A FORTRAN 77 program was developed for the least squares adjustment principles by Observation Equation method for the adjustment and analysis of the observed points. This resulted in realizing the adjusted rectangular coordinates and their equivalent geodetic coordinates data of the positions to monitor the movement of the bridge due to the effect of the dredging activities and other related factors. It is recommended that geodetic data for monitoring of both natural and man-made structures should as a matter of importance be provided as it helps to get early warning signals of dangers and proffer immediate remedial measures.

Keywords: *Baseline data, Deformation, Periodic monitoring, dredging*

1. INTRODUCTION

Deformation implies the change in shape, size and/or figure of an object from its normal to an abnormal state, which may be as a result of forces acting on the object. All large engineering structures are susceptible to movements, which may or may not be within design specifications. As the consequences of failure of such structures are severe, therefore long-term monitoring of operational and regular movement of stress state should be maintained, to ensure that each component of the structure is functioning as intended. In most parts of the world, earthquakes and tectonic movements are known to have occurred with devastating consequences to both human lives and properties. Recent findings have confirmed that Nigeria is not completely immune from this natural disaster, hence the need for constant and continuous monitoring of super-structures and land topography with a view of identifying such areas that are susceptible to unusual movements and also locating earthquake zones.

In deformation monitoring, terrestrial techniques such as precise leveling and/or space-based techniques such as the Global Positioning System (GPS) are most commonly used measurement methods. Deformation has been known to occur in areas where previous mining and dredging activities have taken place and areas where large amount of ground water have been withdrawn for agricultural purposes. In San Joaquin Valley, southwest of Mendota in the agricultural areas of California, years and years of pumping ground water for irrigation has caused the land to drop. U.S. Geological survey,(2006).

Monitoring and analyzing deformations of structures constitutes a special branch of geodetic science. These can be grouped mainly into two as **Geodetic** and **Non-Geodetic** techniques. 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 redundant of observations for the statistical evaluation of the quality and for the detection of errors. They give global information without any check unless compared with some other independent measurements. On the other hand, the instruments, which are used in non-geodetic measurements, are easier to adapt for automatic and continuous monitoring than conventional instruments of geodetic measurements. Geodetic techniques have traditionally been used mainly for determining the absolute displacements of selected points on the surface of the object with respect to some reference points that are assumed to be stable. Non-geodetic techniques have mainly been used for relative deformation measurements within the deformable object and its surroundings (Anonym, 2002).

In Nigeria, the Nigeria Deposit and Insurance Company (NDIC), a multi-storey building gave way partly at the top. The causes of the collapse of buildings have been attributed to poor designs, workmanship and usage of substandard building materials. As it has often been overlooked, deformation has never been thought of and given the proper attention as possible major cause of the collapse of our buildings.
When GPS data are first used for the monitoring of both vertical and horizontal ground movement, the height differences between the monitoring sites, obtained by using both GPS and Leveling measurements, are normally

compared to realize the accuracy of height achieved by GPS .(Ollikainen, 1998).

The Murtala Mohammed Bridge (MMB) was constructed in 1976 by the Federal Ministry of Works. The bridge is located in Jamata district in Lokoja local government of Kogi State. The bridge is 1.76km long and 20m wide. The pedestrian walkway, at both sides of the bridge, is 2.0m wide. The lane demarcation divides the bridge into two lane roads, and is lined with flood lights located at intervals throughout the length .The lane width is 8.0m each. The bridge is suspended by a total of fifteen (15) concrete reinforced columns. A sketch diagram (not to scale) is presented in Fig 1.

Most of the country's shipments from the seaports are transported hinterland is by roads. The uses of these roads were so enormous that, the roads are over stretched and so they are generally in bad condition and shape.

Though, Nigeria has the largest road network in West Africa, it is poorly maintained and often cited as a cause of the country's high rate of traffic fatalities. The rainy season and poor equipments used posses a major challenge to the Roads maintenance agencies.

It is evident that, some paved roads lost their asphalt surface and are in very poor conditions or have reverted to being gravel roads. Some of the roads system is barely usable, especially in the high rainfall areas of the south.

In the railway sector, years of neglect of both rolling stock and right of ways have seriously reduced the capacity and utility of the system.

In order to fulfill the mandate of National transport policy regarding inland water ways in respect of transporting persons and goods, all year round navigation of the rivers and the promotion of public and private investment in that sector. Attempts were made first in 1958, then 1978 to dredge the lower river Niger. However, it was in 1996 that the then Federal Military Government approved of the dredging of the lower Niger. The dredging project is to cover 572km from Warri in Delta State to Baro in Niger State. Though, the exercise could not take off at the year of its proposal but later in the year 2009.

Consequently, the dredging exercise would have impact on the bridge; it has become imperative that an immediate study be conducted on the bridge to ascertain its stability and to monitor the impact of the deformation on the existing structure.

The aim of the study is the establishment of a base line data for a period tic monitoring of deformation on Murtala Mohammed Bridge as the river Niger dredging project has already commenced. The aim would be achieved through the following objectives:

i. Establishment of first order geodetic controls, outside influence area of the bridge.
ii. Mark-out permanent monitoring points along side of the bridge (i.e. suspected areas of influence).
iii. To carry-out (DGPS) observations on the marked out monitoring points.
iv. Development of Fortran77 program based on the least squares adjustment.
v. Make necessary recommendations on the analysis of the result to the Federal Ministry of Works to take up necessary actions on the observed results.

The study is intended to establish base line data by means of establishing first order GPS control points outside the influence area of the bridge and on the bridge so that subsequent studies of deformation of the bridge can be based on. This is to put in place effective early warning signals in case there is any noticeable change or movements on the structure. Deformation monitoring system provide a practical control of a hazard related to position change or failure of a structure, which can reduce risks exposure before and during construction and throughout the life cycle of the structure and hence decrease the insurance premium and disasters to life and properties. The Study area is located in Jamata district in Lokoja local government area of Kogi State. The structure monitored was Murtalar Mohammed Bridge (MMB)The bridge links Lokoja and Katon-Karifi local government area of Kogi State. The bridge lies between latitude 08^0 02' 30'N' and 08^0 04' 10''N of the equator and between longitude 06^0 44' 00''E and 06^0 46' 50''E of the Greenwich meridian. The bridge is a major link connecting the south-western Nigeria with the Federal Capital, Abuja and the Northern parts of Nigeria.

The scope of the study is limited to the monitoring of deformation of Murtalar Mohammed Bridge, using GPS observation techniques for a periodic monitoring of the deformation/subsidence of the structure. This would include the following; Carry-out GPS observations (Static-mode) on the marked out monitoring points.

Reconnaissance for this research work was carried out in order to acquire the necessary data for planning and determing the best and economical survey technique to be employed. This aspect of the project is very important for the execution of the research work. A complete recce is a prerequisite for effective data collection. During recce, an overall picture of the project site were obtained by physical inspection of the structure (Bridge) and the location of the existing control points planned for use in the research work. The control points were checked and found to be insitu and therefore suitable for coordination. Also, considered for the study, was the equipments to be used, the accuracy required the logistics and the method to be used.

The project was categorized into two during the reconnaissance i.e;

I. Office Planning
II. Field Reconnaissance.

During the Office Planning, it is essential to assemble and analyzed all available data/information, related to previous surveys conducted in the study area. These data include, available Maps/Plans of the study area, coordinates of the existing controls located in the study area and other related

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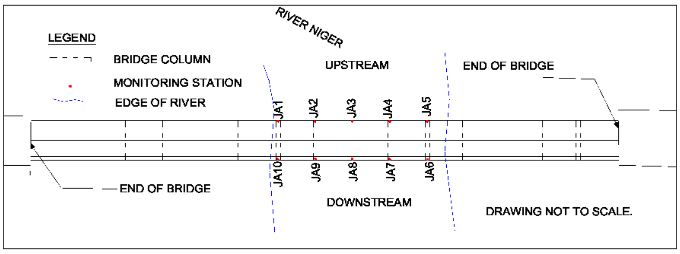
data. Other preliminary office planning includes, site inspection, logistics that involve, transportation of personnel and equipments to the site and the estimated distance from lokoja town to the study area Jamata which is about 30km.
The field recce survey commenced on the 10/10/2009.The position of the existing first order control points were identified and located. The following control points were identified and confirm to be insitu.
+ U70 (Located on the top of Mount Patti about 3.5km from the FM radio house).
+XSP 23. (Located, about 6m away from NNPC delivery line Signboard, Upstream).
+VON-B (Inside Van –oord ,Dredging Company site Office, Lokoja).

+XSP 24 (Located within Farmland Upstream of river Niger).
The coordinates and heights of the control points were obtained from the Federal Surveys Makurdi and the Nigerian Inland Waterways Authority (NIWA) in Lokoja were used to establish the monitoring points on the bridge.

The criteria required for optimum results of observed data were considered, in the course of determing the positions of MBDC1, MBDC2, MBDC3 and MBDC4.

For long term monitoring, the stations were spatially distributed on top of the bridge directly atop the bridge column. A total of ten (10) stations were marked out, as indicated in Fig 1.



The stations are positioned at points (Columns) that have the potential of exhibiting any predictable behavior of the structure. The stations are inserted using nails, as described in later in this paper, on the bridge with identification numbers from AJ01 to AJ010. Each of the columns has two pairs of the monitoring stations.

Monumentation of Control Stations

The newly established control stations (MBDC1, MBDC2, MBDC3 and MBDC4) were constructed using the SURCON standard. The stations have a brass-nail set at the centre of the concrete pillar, re-enforced with a 38mm diameter x 1000mm length of galvanized iron pipe running through the centre of the concrete mortar into the ground leaving a 50mm length protruding above the top of pillar surface with a proper pillar identification number clearly imprinted on the top. The controls were constructed of concrete mortar mixed in the proportions of one (1) part of cement to two (2) parts of gravel to three (3) parts of sharp sand, and not less than 300mm x 300mm at the top cross- section, 500mm x 500mm at the bottom section, 200mm above and 500mm below the natural ground level (NGL). The stability of these control points are ensured as they were positioned on rocky topography.

Emplacement of Monitoring Stations

It was found during the reconnaissance exercise that emplacement of the monitoring stations on the structure (Bridge) was difficult. The reinforced concrete was hard to drive in nails. More so, the stations were to be emplaced in such a manner that they are not exposed on the surface to avoid been knocked off by pedestrians and can easily be occupied during GPS observations. In emplacing the monitoring stations, a drilling bit of 2mm diameter, using a hand drilling tool, was used in drilling a hole of about 4mm depth at each of the ten (10) stations directly atop the supporting columns. Small nails were then inserted into the holes and filled up with super-glue. The nails were put at level with the concrete surface. Red paint was used in circling the points. The identification numbers were written close to the point (Plate 1.0).

Plate 1.0: Monitoring stations identification numbers

Adjustment and Calibration Test of Instruments

Calibration and Test are necessary for the elimination of systematic error and to ensure confidence in the system. In order to ascertain the reliability of the raw measurement obtained from the observation, the calibration and checks of the GPS Receivers instrument to be used, was carried out using standard control. Points (U70 and VON-B). Due to wear, change in structure of the materials used in construction, and sometimes rough usage, the relationships between the various parts of the instruments undergo slight changes in the course of time. Hence it is essential, before using any instrument, to ensure that it is in proper adjustment and in good working condition. This is to guaranty high precision and accuracy of the controls and monitoring stations established which are to serve as a baseline data for monitoring deformation and subsidence monitoring of the bridge.

Fig. 1 Identification of locations of Monitoring Stations

Plate 2.0: First Order Trigonometric Station used in carrying out Field observations

Observational Procedures of Baseline Establishment

(A) **Differential GPS (DGPS).**

This is when the position of one GPS receiver is determined relative to another receiver. The method involved positioning one receiver on a known point and determining the position of other receivers relative to the known point. Differential positioning allows one to overcome the effects of environmental errors and selective availability (SA) on the GPS signals to produce highly accurate position fix by determining the amount of the positioning error and applying it to position fixes that were computed from collected data. It should be noted that positioning errors are the same for two GPS receivers in the same area since the receivers receive signals from the same satellites at the same time.
The static survey/stationary differential method was used in the observations. This involves collection of positioning data by GPS receivers for a longer period of time. This method was used to establish control points on long lines, it required long observation times and provides the highest accuracy.

Validation Tests of Gps Receivers And In-Situ Checks On Controls

In the planning phase of a GPS project the procedures and equipment to be used, from data collection to the final product, were tested to ensure they reliably satisfy the desired accuracy requirements. This testing is referred to as the *Validation Process.*

The validation process was carried out using the receivers on *Differential (DGPS) mode*, and the collection of positioning data by the GPS Receivers was on Stationary Static. The field work consisted of setting up and logging data from one GPS receiver at the reference station (U70) and a rover receiver at the 'slave' station (VON-B) after configuration of the controllers.

Data Collection with GPS

The following specifications were adopted in the observation and processing of the DGPS data:First order GPS Control Survey:

a) The existing first order GPS control stations (U70 and VON-B) identified. Also new controls were established i.e (MBDC1, MBDC2, MBDC3 and MBDC4) on stable grounds outside the area of influence of the bridge.
b) Appropriate station descriptions were conducted on an appropriate station description form for each of the controls.
c) The GPS observations (for both the monitoring stations and controls) were conducted using the Static Differential method of the global positioning system (GPS) in the 3-D, UTM projection of the WGS84 ellipsoid, with the altitude reference at elevation above Mean Sea Level (MSL).
d) The observations were conducted in loops and connected to at least two (2) control stations. The station occupation time was between two (2) hours and one and half (11/2) hours for a good weather.
e) The post-processing of the acquired data were conducted to generate the list of the WGS84 ellipsoidal coordinates. The geodetic and Cartesian coordinates, was transformed into Minna Datum coordinates. The conversion factors and geodetic parameters necessary for a successful small scale monitoring using GPS for bridges and other engineering structures (Watson and Coleman,1998).

Procedures for DGPS Observations

(1) After the configuration of the GPS Controllers as enumerated earlier, the GPS equipment was then set-up by screwing the Sensors to the Quick-Stands (Bipods) with the Controllers attached. The batteries were also connected to the Sensors and Controllers.
(2) The Quick-Stands were set-up over the Stations (Points) and leveled accurately. The set-up for the Reference Station (Controls) was first carried out and the Rover was subsequently set-up at the Remote Stations. The Antenna heights at the respective stations were measured and documented.
(3) Logging of data was carried out simultaneously at both the Reference Station and Remote Stations. Throughout the duration of the observation, the GPS set-up at the Reference Station remains permanently at its position, while the other set-up was moved to occupy all the various stations in the network of the loop. An Assistant Surveyor was positioned toman the 'Master' Receiver, for security reasons and to restart immediately, in the event of a

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failure or shutdown of the receiver for any reason whatsoever.

(4) In each of the GPS set-ups for all the stations, the following information was recorded: date of observation, project names/title, base station identity, model and serial number, data file name, remote station id, Antenna height, start time, occupation time, name of operator, arrival time (local and UT) and stop time.

Data Analysis

The Raw survey data gathered in the course of the fieldwork were converted into meaningful values during the data processing stage to obtain the co-ordinates and heights of the new established control points and the monitoring stations on the bridge.

The stages followed in data analysis are:

- Processing of DGPS data,
- Abstract of the co-ordinates and Heights of the control stations and monitoring points.
- Least square adjustments using Observation Equation methods were adopted and this involves the statistical analysis of data and development of FORTRAN program. Final co-ordinates of Control stations and Monitoring Points with associated Statistical Parameters.

Processing OF DGPS Data

After each day's field work, GPS data are downloaded into the computer and processed. The software used was GNSS Solution-Magellan Navigation. The GNSS Solution runs under Microsoft Windows and is built out of different components in a clear logical way. The GNSS Solution's algorithm sped up GPS survey using short observation time providing millimeters accuracy on lines up to about 15 km.

Least Squares Adjustments by Observation Equation Methods

The coordinates of nineteen points including the monitoring stations and controls were adjusted using the observation equation model. To do this, the GPS processed vectors (baseline vectors) of the points were adjusted which were later transformed to adjusted coordinates of the points. The following functional relationship between adjusted observations and the adjusted parameters were involved:

$$L_a = F(X_a) \qquad (1)$$

Where L_a = contains the adjusted vector of observations and X_a = adjusted station coordinates. Equation (1) is linear function and the general observation equation model was obtained.

$$V = AX + L \qquad (2)$$

Where A = design matrix; X = vector of unknowns and L = vector of approximate minus observed values. For chosen Cartesian coordinates, the parameterization of receiver positions, the vector observations between stations k and m is shown below:

$$\begin{pmatrix} \Delta U_{km} \\ \Delta V_{km} \\ \Delta W_{km} \end{pmatrix} = \begin{pmatrix} U_k - U_m \\ V_k - V_m \\ W_k - W_m \end{pmatrix} \qquad (3)$$

The portion of the design matrix A is

$$A_{km} = \begin{pmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 \end{pmatrix} \qquad (4)$$

The coefficients are either 1,-1 or 0.Each vector contributed three rows to the design matrix.

The FORTRAN program was written employing inner constraints solution and compiled with FORTRAN FORCE 2.0 compiler. Due to rank deficiency, a pseudo inverse was computed. All error editing and corrections were carried out and the program ran successfully. The main reason for inner constraintssolution is that this type of adjustment is important for the quality control of observations.

Then, it is necessary to adjust GPS coordinates of the points to achieve consistency and to provide good and solidgeodetic framework on which all other or future observations can be based upon. The weight matrix was determined from the standard error of the observations. i.e. $P = 1/a^2$ where a is the standard error of each of the processed vector components. The adjusted X, Y and Z coordinates equivalent geodetic coordinates of the stations are shown in Table 1 below:

Table 1: Adjusted X, Y, Z and Geodetic Coordinates

STATION	X	Y	Z	Latitude	Longitude
U70	6276565.136	738769.393	860772.538	07º 48' 27.409"	06º 42' 46.756"
VON-BASE	6276406.184	741301.052	857294.349	07 46 34.629	06 44 09.421
SP 1	6274489.014	743348.332	869150.178	07 53 04.320	06 45 23.135
SP 2	6273000.259	743864.537	879319 .961	07 58 38.552	06 45 45.592
XBJ 1	6271833.542	744391.598	887284.725	08 03 00.251	06 46 07.172
JA 1	6271723.839	744686.208	887699.260	08 03 13.949	06 46 17.149

JA 2	6271711.967	744748.837	887769.166	08 03 16.222	06 46 19.226
JA 3	6271695.830	744814.595	887839.223	08 03 18.518	06 46 21.421
JA 4	6271677.691	744881.756	887903.337	08 03 20.630	06 46 23.669
JA 5	6271656.685	744947.504	887971.228	08 03 22.878	06 46 25.882
JA 6	6271661.142	744961.455	887957.408	08 03 22.405	06 46 26.317
A 7	6271678.875	744894.210	887891.434	08 03 20.234	06 46 24.068
JA 8	6271697.011	744829.902	887824.813	08 03 18.040	06 46 21.913
JA 9	6271713.016	744761.845	887757.013	08 03 15.819	06 46 19.644
JA 10	6271729.834	744694.075	887681.648	08 03 13.350	06 46 17.381
MBDC 1	6272405.902	742322.862	884869.718	08 01 40.935	06 44 57.882
MBDC 2	6272392.540	742493.724	884814.884	08 01 39.137	06 45 03.475
MBDC 3	6271348.173	746274.514	889056.197	08 03 58.528	06 47 10.107
MBDC 4	6271361.838	746328.747	888906.879	08 03 625	06 47 11.813

Problems and Constraints Encountered

A project of this nature is not without accompanying problems and constraints. They came in the following forms:

i. Weather conditions: the field work was carried out during the rainy season. This hampered field operations as in some occasion, work had to be terminated as a result of rain. Since it is not advisable to operate survey instrument under the rain due to its effect, observations had to be stopped thereby reducing the man-hour period for the work on some days.
ii. Difficult topography: the project area was associated with difficult rocky terrain. Accessing the control points, most especially U70, on mountain Patti was quite challenging and difficult. The meandering route and high land leading to the control points was difficult.
iii. High vehicular traffic: the Abuja-Lokoja road is known for very high vehicular traffic as vehicles move in and out of the nation's capital. The peak of the traffic is most noticeable during noon period. The dense traffic resulted in vibration on the bridge structure. This in turn affected observations as the instrument in some cases became unstable. This led to restricting the time of field work to the morning period (6.30am to 11.00am) and evening period (3.30pm to 6.30pm). The safety of the field personnel along the busy road constituted a constraint in executing the project.
iv. Financial challenges: the high cost of finance involved in the execution of the work constituted a very serious challenge. The logistic demands throughout the period of the field work were quite enormous.

However, all these constraints and problems encountered paled insignificance as the aim and objectives of the projects were achieved.

2. CONCLUSIONS &RECOMMENDATION

While humans undergoes periodic medical checks to ascertain their health conditions, its expedient that super-structures are periodically monitored in order to determine the state of such structures to avert structure failures which normally leads to unquantifiable loss of lives and properties with its associated environmental consequences. Precise "Control Stations" established are needed in the monitoring of these structures.

The monitoring of Super-Structures is not readily encouraged by relevant agencies in the Country. As a result of this neglect, so many lives have been lost and also properties worth billions of naira destroyed due to structural collapse. The reliability of results of structural monitoring is directly tied to the accuracies and precisions of the Controls used in carrying out the monitoring. It is expedient, therefore, to establish highly reliable Controls outside the influence areas of the structure in other to guaranty and rely on the results obtained.

While the work described in this thesis has been largely practical rather than academic in nature, it has led to a number of findings that may be of interest to future researchers. These findings, along with recommendations for further work are presented in the following paragraphs.

The following are the recommendations made by the Author based on the experiences gathered in the course of executing the project.

- "Monitoring of high rise buildings, super-structures, and general environmental monitoring of certain areas to determine the tectonic movement over time to serve as early warning signal must be put in place by relevant agencies. This will require the establishment of 'Control Stations' at appropriate locations within the vicinity of the structure. Planning, specifically layout plans; architectural designs and sub-structural design of buildings must be based on a topographical survey plan produced by a surveyor.
- "Topographical survey plan produced by a surveyor, showing all information of site and adjoining site, hydrological information, storm water discharge point, vegetation type,

infrastructural details within and around the site, soil and geotechnical information where available that will assist various professionals in the construction industries to produce economic and appropriate construction design, must be made a prerequisite for building approval.

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"As-built survey should form part of the requirement of building construction and no construction should be deemed complete without the as-built survey.

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