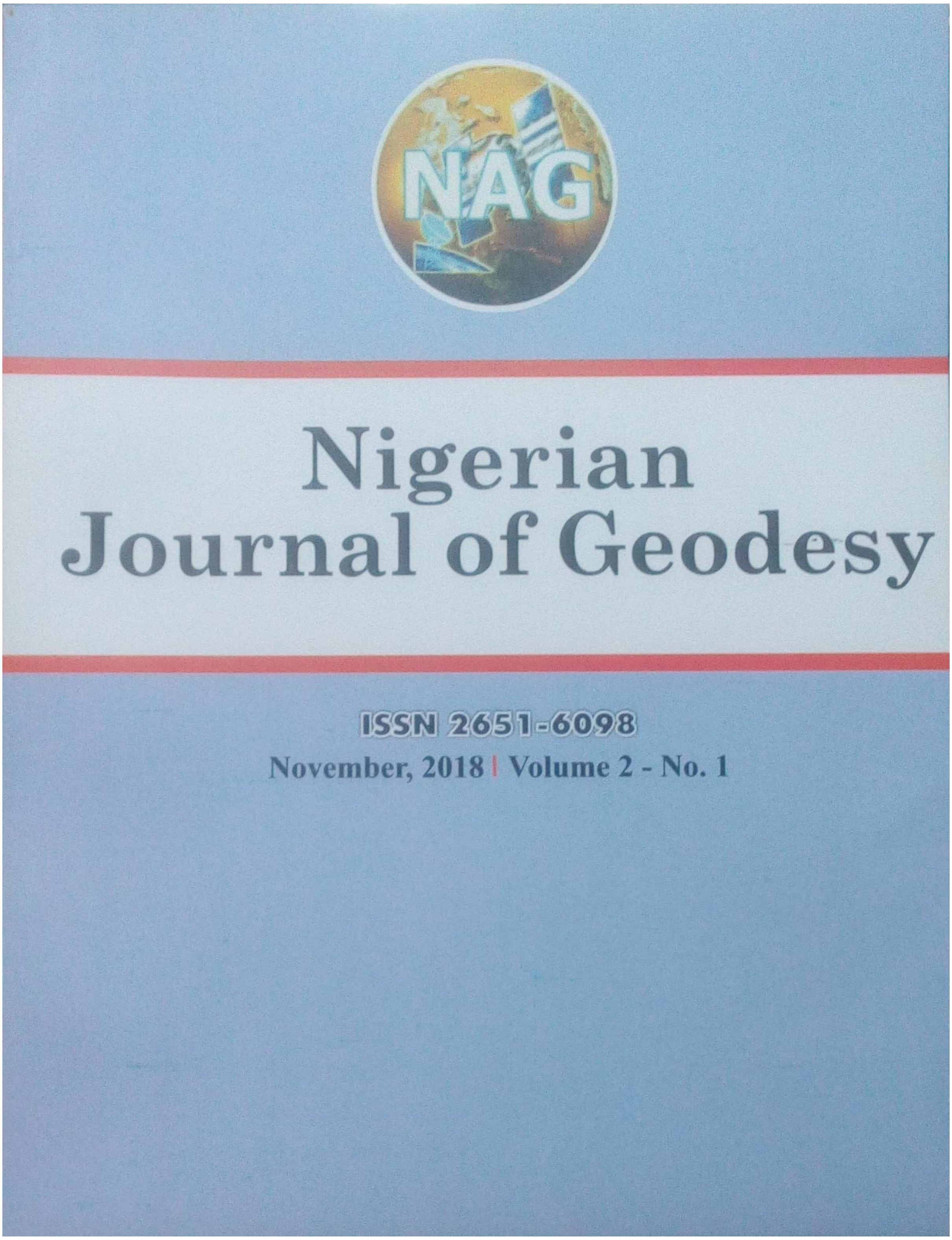
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MONITORING AND ANALYSIS OF DEFORMATION OF IKPOBA RIVER BRIDGE, BENIN CITY, EDO STATE, USING GLOBAL POSITIONING SYSTEM

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ABSTRACT

Safety is the primary and most important reason for monitoring the deformations of engineering structures. It could also help in improving our knowledge of the mechanical behaviour of engineering structures. Engineering structures are subject to deformation due to factors such as changes of ground water level, traffic load changes, tidal and tectonic phenomena. The Ikpoba River Bridge in Benin City whose traffic load has increased was monitored using GPS technology. The bridge was investigated as a result of carrying more load than usual due to the expansion of the road and dredging activities that had taken place in the river in 2008. One reference station and six monitoring points were involved in the monitoring of the bridge. The regularity of the survey was thirty days, and six observation epochs were used. Each monitoring point was occupied for about thirty minutes during the observation. The observation data were processed with compass software. The processed coordinates were adjusted with least squares adjustment technique. The standard deviation of unit weight for the weighted observations (σ_o) was computed for each observation epoch and was less than 1cm. The observation epochs were compared consecutively by finding the difference between successive observation results. The maximum differences in coordinates of the successive epochs were all less than 1mm. It was seen from the results that the bridge was stable and did not undergo any displacement/movement within the period of study. It is recommended that the results of the six monitored points on the bridge should be further analyzed using other appropriate model of adjustment technique.

Keywords: *Deformation, Monitoring, Epoch, Coordinates, Accuracy*

1. INTRODUCTION

Safety is the primary and most important reason for monitoring the deformations of engineering structures (Gikas and Sakellariou, 2008). A secondary reason is the need for improving our knowledge of the mechanical behaviour of engineering structures. Such knowledge enhances our understanding of the basic design concepts, which gradually leads to more effective constructions. Engineering structures (such as dams, bridges, viaducts, high rise buildings, etc.) are subject to deformation due to factors such as changes of ground water level, tidal phenomena, and tectonic phenomena (Erol, et al, 2006). Deformation can also occur in areas where previous mining activities and dredging have taken place and areas where large amount of ground water has been withdrawn. Monitoring and analyzing deformations of these structures constitutes a special branch of Geodetic Science. There are several techniques for measuring the deformations. These can be grouped mainly into two as geodetic and non-geodetic techniques.

Each main measurement technique has its own advantages and disadvantages. Geodetic techniques, through a network of points interconnected by angle and/or distance measurements, usually supply a sufficient redundancy of observations for the statistical evaluation of their quality and for a detection of errors. They give global information on the behaviour of the deformable structure while the non-geodetic techniques give localized and locally disturbed 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 been traditionally 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).

The design of monitoring scheme should satisfy not only the best geometrical strength of the network but should primarily fulfill the needs of subsequent physical interpretation of the monitoring results. Selection of monitoring techniques depends heavily on the type, the magnitude and the rate of the deformation (Aziz et al, 2001). The determination of deformations according to geodetic techniques constitutes terrestrial measurement techniques or space based positioning techniques and/or combination of both techniques. However, with the advent of GPS measurement technique in geodetic and surveying applications, this very precise satellite based positioning technique has become useful in deformation measurement (Ono, 2013). The technological developments in high precision point positioning systems together with no-human data transmission techniques without any atmospheric obligation, have led to easy adaption of such monitoring systems for the objects in question (Akyılmaz, et al, 2005). With the development of Global Positioning System (GPS), the sampling frequency of GPS receiver can reach about 20 times per second, while the location precision can approach 5~10 mm. So, GPS can be used in the displacement monitoring of large structures (Jianjing, et al, 2002).

The carrier phase double difference mathematical model can be adopted to monitor the structures with GPS. This model can remove the error between the clocks in the satellite and the receiver because the errors of orbit and atmosphere are connected with the distance between the datum point and monitoring point, a GPS receiver antenna should be placed near the target bridge as a reference station. This point should be stable, and there are no buildings above 5° to envelop or reflect signals. Another GPS receiver antenna should be placed on the monitoring point. At least 5 satellites signal should be received at the same time, and the data is stored in the computer. When the data is processed, the displacement of each time point can be obtained (Jianjing, et al, 2002). The horizontal and vertical displacement of bridges can be computed by coordinate projection and translation. In DGPS positioning, we usually assume the position of the reference station is exactly known in WGS 84 (Ono, 2013).

Global Positioning System offers advantages over conventional terrestrial methods. Intervisibility between stations is not strictly necessary, allowing greater flexibility in the selection of station locations than for terrestrial geodetic surveys. Measurements can be carried out during night or day, under varying weather conditions, which makes GPS measurements economical, especially when multiple receivers can be deployed on the structure during the survey (Abdullahi and Yelwa, 2016).

The aim of the study is to monitor Ikpoba River Bridge in Benin City with a view of detecting any change or displacement taking place using DGPS. The objectives are:

i. To determine the 2-D coordinates (Northings and Eastings) of the selected points (monitoring point) on the bridge.
ii. To carry out statistical analysis on the six epochs of observations using least squares (Observation Equation) adjustment technique.
iii. To determine the displacement/movement of the bridge by comparing the results of observations.

The Study area is located along Apkakpava road in Ikpoba Okha Local Government Area, Benin City Edo State. The bridge is located at the beginning of the Benin-Asaba road in Benin City. It is a 4 No. 15m span right bridge (total length 60m) with cross-sectional width of 13m. It has a concrete slab deck supported by 7 No. universal steel beams resting on reinforced concrete piers and abutments. The bridge was constructed in 1972 by Monier Construction Company Nigeria Limited on the contract agreement with the Federal Ministry of Works for the Government of Nigeria. The bridge lies between latitudes 06º 11’ 05.41”N and 06º 12’ 06.13”N and longitudes 05º 42’ 48.62”E and 05º 43’ 49.89”E. Figures 1a to c show the maps of the study area.

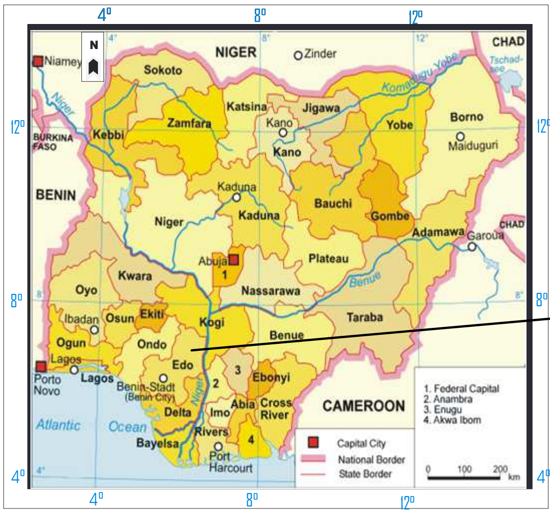

Fig. 1a: Map of Nigeria Showing Edo State.
Source: Ministry of Lands and Surveys, Benin City

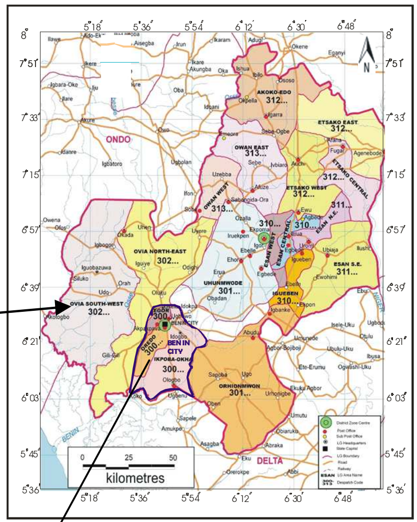

Fig. 1b: Map of Edo State Showing Benin City.
Source: Ministry of Lands and Surveys, Benin City.

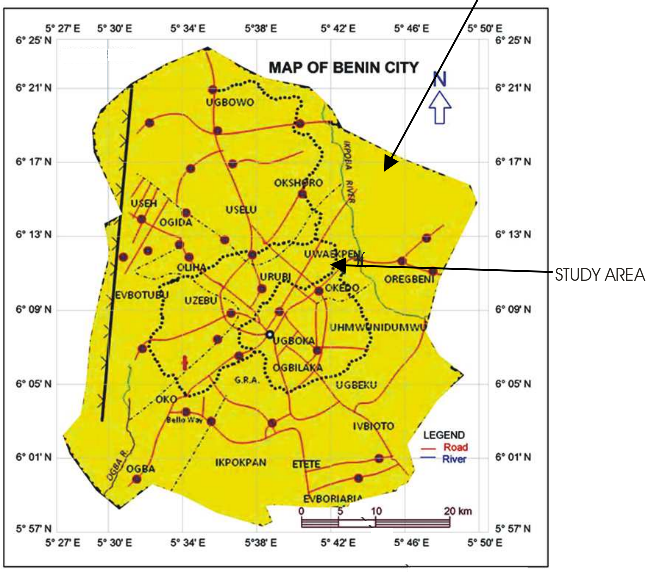

Fig. 1c: Map of Benin City Showing Study Area
Source: Ministry of Lands and Surveys, Benin City.

This study was concerned with the monitoring of the Ikpoba River Bridge in Benin City by establishing geodetic controls outside influence area of the bridge, marking out permanent monitoring points on the bridge (i.e. suspected areas of influence), carrying-out (DGPS) observations on the marked out monitoring points, processing the observed DGPS data, least squares adjustment of processed observations, evaluation of deformations, and making necessary recommendations with respect to the obtained results.

Deformation Analysis

According to Uzodinma (2014), deformation analysis is the study of the changes in the shape of an arbitrary body in time. In surveying it is the observations of the geometrical changes of a body. It involves the comparison of observations from different epochs. Bayrak (2008) stated that the analysis of deformations of any type of a deformable body includes geometrical analysis and physical interpretation. Geometrical analysis describes the change in shape and dimensions of the monitored object. The ultimate goal of the geometrical analysis is to determine in whole deformable object the displacements and strain fields in the space and domains. Physical interpretation is to establish the relationship between the causative factors (loads) and the deformations. This is determined by statistical method, which analyses the correlation between the observed deformations and loads (Chrzanowski et al, 2005 and Bayrak, 2008).

Least Squares Adjustments by Observation Equation Method

According to Ono et al (2014), the following functional relationship between adjusted observations and the adjusted parameters are given as follow:

$$L_a = F\,(X_a) \tag{1}$$

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

$$V = AX + L \tag{2}$$

Applying least squares principles and solving for X, we obtain

$$X = -\,(A^TPA)^{-1}\,(A^TPL) \tag{3}$$

Now if $N = A^TPA$

$N^{-1} = (A^TPA)^{-1}$ and $U=A^TPL$

Where A = design matrix; X = vector of unknowns, P= Weighted Matrix 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:

$$\begin{pmatrix} \Delta U_{km} \\ \Delta V_{km} \\ \Delta W_{km} \end{pmatrix} = \begin{pmatrix} U_k - U_m \\ V_k - V_m \\ W_k - W_m \end{pmatrix} \tag{4}$$

The extract of the observation equations and the matrix form of the equations using least squares model are respectively equations (5) and (6).

$$\begin{aligned} N_A &= N_G + \Delta N_{GA} + V_1 \\ E_A &= E_G + \Delta E_{GA} + V_2 \\ N_B - N_A &= \Delta N_{AB} + V_3 \\ E_B - E_A &= \Delta E_{AB} + V_4 \end{aligned} \tag{5}$$

$$\begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \end{pmatrix} \begin{pmatrix} N_A \\ E_A \\ N_B \\ E_B \end{pmatrix} + \begin{pmatrix} N_G + \Delta N_{GA} \\ E_G + \Delta E_{GA} \\ \Delta N_{AB} \\ \Delta E_{AB} \end{pmatrix} \tag{6}$$

Standard deviation of unit weight for the weighted observations (σ_o) is given as:

$$\sigma_O = \pm\sqrt{\frac{V^T PV}{r}} \tag{7}$$

Where,

V = Vector of Residual

P = Weight

r = Degree of Freedom or Redundant Observation

2. METHODOLOGY

The adopted methodology involved the following stages, namely: data acquisition, data processing, and data presentation. Figure 2 shows the flow chart of the adopted methodology.

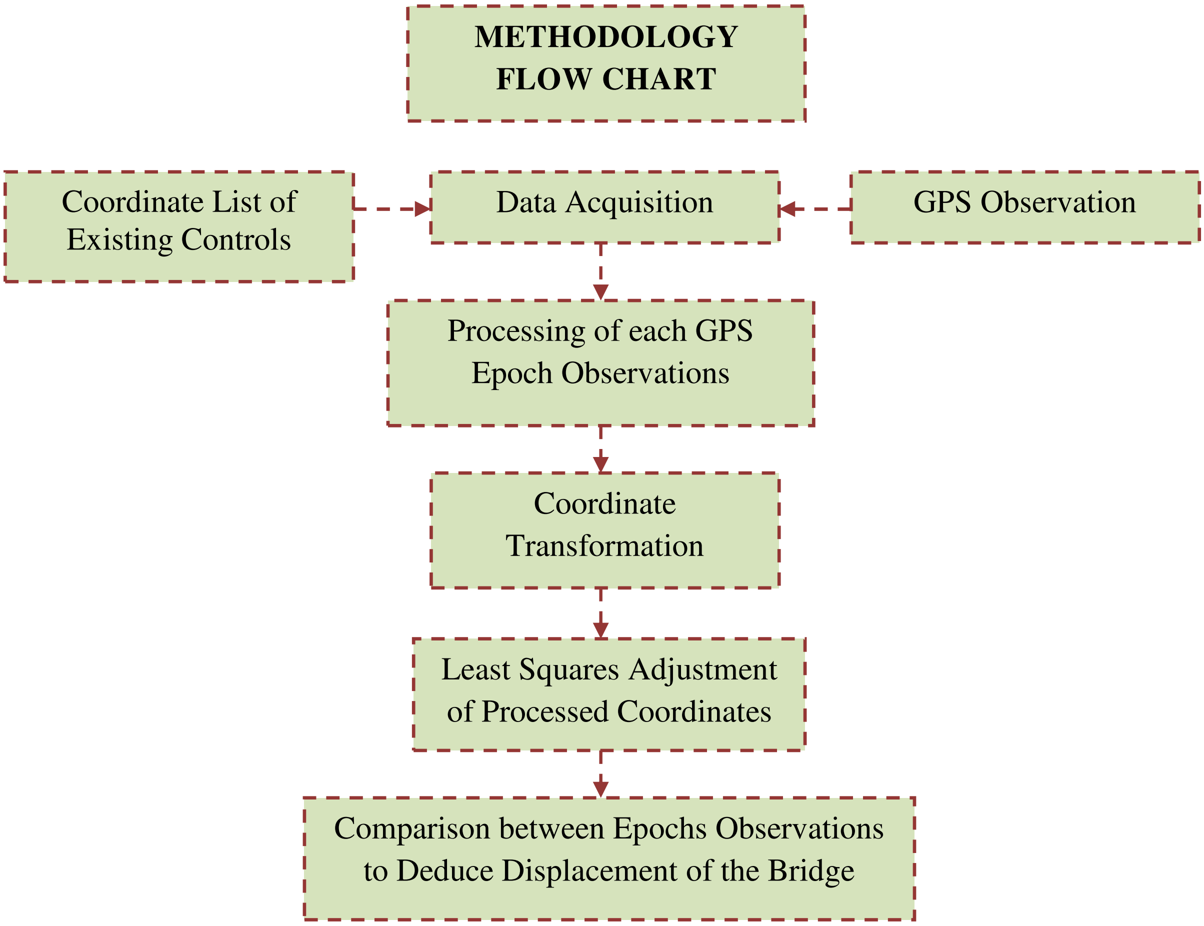

Fig. 2: Methodology Flow Chart

2.1 Method of Data Acquisition

Reconnaissance

The study area was visited and suitable points were chosen and marked with concrete nails on both sides of the bridge. A wooden peg was also placed at a suitable point outside the bridge to depict the position of the reference point that was established. Nearby controls were also located and their coordinates were obtained from the Edo State Ministry of Lands and Surveys, Benin City.

Monumentation

A pre-cast property beacon with dimensions 25cm x 25cm x75cm was used to replace the wooden peg that was fixed at the selected reference point outside the bridge during reconnaissance. The beacon was capped with a mixture of cement, sand and water and a number (AHO 001) template was engraved on it.

Procedure for Differential GPS Observation

The DGPS was used for the acquisition of the 2-D coordinates (Northings and Eastings) of the monitoring points. The observation was carried out in post-processing static mode with the base receiver at the control station (CFG 121^A) (Figure 3) and the rover receiver at the reference station (AHO 001) outside the bridge (Figure 4). Having established the position of the reference station, the base receiver was moved to the reference station while the rover receiver was moving from one of the monitoring points on the bridge to another (Figure 5). The procedure was repeated for the other epochs of observation (five epochs) for the monitoring points on the bridge. The regularity of the survey was one month and there were six epochs of observation.

Fig. 3: Base Receiver at Control Station CFG 121^A.

Fig. 4: Rover Receiver at Reference Station AHO 001.

Fig. 5: Rover Receiver at One of the Monitoring Stations on the bridge.

2.2 Data Processing Procedure

Processing of Raw Data

The GPS data were downloaded into a computer system by direct cable connection from the DGPS to the computer system using HcLoader Software. The downloaded data were processed and adjusted with Compass software.

The processing and adjustment of the GPS data using the Compass software involved the following steps:

1. The Compass Post Processing software was launched on the computer system.
2. The GPS raw data were imported into the compass environment by selecting import in the file menu.
3. Station was selected at the top left hand side of the software environment, 'base data' was right clicked to select properties, in properties, the following were set:

i. sample interval = 5
ii. max epoch = 9999
iii. elevation mask (degree) = 20 and
iv. ok was clicked

4. File menu was clicked to select process all and the data were processed.
5. Tool menu was clicked to select coordinate system manager; in the coordinate system manager, Clarke 1880 was selected under ellipsoid. The Nigeria West Belt was added by setting the following in the projection module (Transverse Mercator):

i. Scale Factor = 0.99975000
ii. Origin Latitude = 4° 00’ 00”
iii. Origin Longitude = 4° 30’ 00”
iv. False Northing = 0
v. False Easting = 230738.266
vi. ok was clicked
vii. The added datum (Nig-West Belt) was selected in the coordinate system management and ok was clicked.

6. Also in tool menu, datum modify was clicked to select datum convert and the following seven datum transformation parameters were entered:

TX = 92m

TY = 93m

TZ = -122m

RX = 0 (arc second)

RY = 0 (arc second)

RZ = 0 (arc second)

Scale factor = 0 (ppm)

7. Adjustment menu was clicked to select setup submenu, in the setup submenu, 3D, 2D and Height Fitting were selected, also, in free data adjustment submenu, the base station was selected and ok was clicked.
8. Run (W) was selected in the adjustment menu to finally process the data.
9. The result menu was then selected to display the processing results.

Least Squares Adjustment of the Processed and Adjusted Coordinates

The processed coordinates (six epochs) were adjusted using least squares adjustment method (Figure 6). The weight of each observation epoch was computed by finding the reciprocal of the variances obtained from the variance covariance matrix of the processed GPS observations using the Compass software. The least squares model used for the adjustment is given in equation (2). A design matrix of 28 ×12, matrix of unknown of 12 × 1 and residual matrix of 28 × 1 were used for the adjustment. The a posteriori standard error for the weighted observations (σ_o) was computed using equation (7).

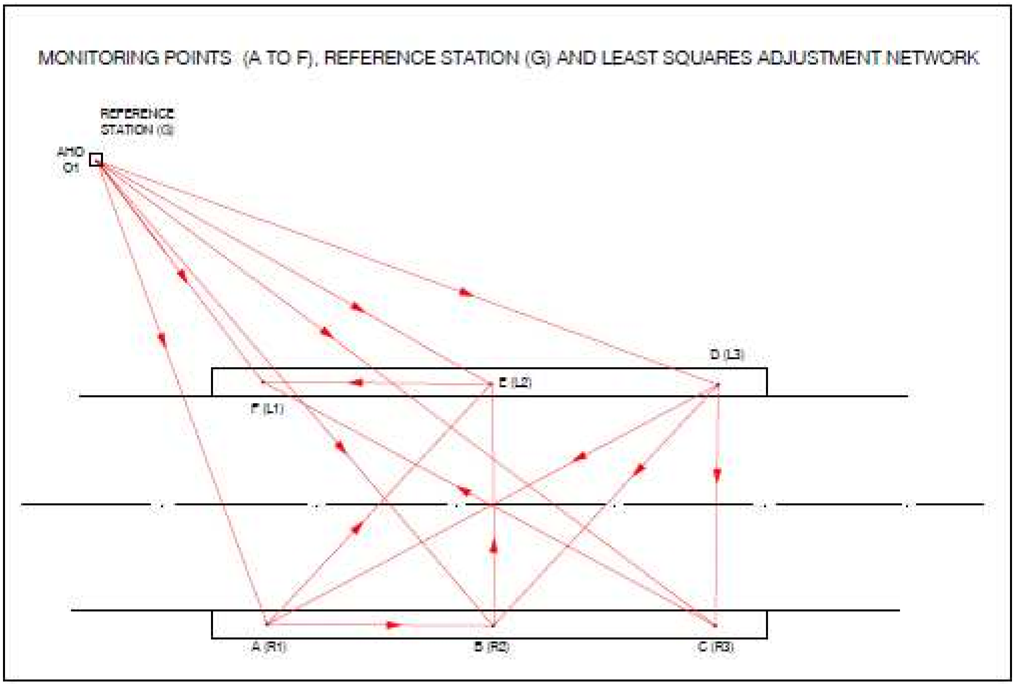

Fig. 6: Least Squares Adjustment Network

Deduction of the Displacements/Movements of the Bridge

The processed and adjusted coordinates (six epochs) were typed in Excel spreadsheet and compared by finding the differences between consecutive epochs of observations to see if there was displacement/movement within the period of monitoring.

2.3 Results Analysis

Discussion of the DGPS Results

The DGPS observations were carried out in six difference epochs. In each epoch of observation, each of the monitoring station was occupied for about 30 minutes. Each observation epoch was processed as a separate loop. From the processing results, the six epochs observations were seen to have passed the Network Adjustment Test. That is, the normal matrix generated was a regular one and inverted accordingly for calculation of residuals.

Discussion of the Adjusted Coordinates Using Least Squares Technique

The DGPS data of the six epochs observations were processed with compass software and adjusted using least squares adjustment method. The maximum residuals from the first epoch to the six epoch observations are respectively -0.0008m, 0.0001m, -0.0003m, -0.0002m, -0.0002m and -0.0006m. The standard deviation of unit weight for the weighted observations (σ_o) from the first epoch to the six epoch observations are respectively ±0.0035m, ±0.0043m, ±0.0043m, ±0.00107m, ±0.00132m and ±0.00523m and are less than 1cm, showing the high precision of the observations.

Comparison between the Consecutive Adjusted Epochs Observations

The DGPS observations (six epochs) were adjusted using least squares technique. The adjusted coordinates were compared consecutively by finding the differences between successive epoch observations. Also, the differences between the first and the sixth epochs observations were computed (Table 1). It is seen from table 1 that the maximum differences between the first and the second epochs observations in northing and easting are -0.0008m and 0.0008m, the second and the third are -0.0004m and 0.0004m, that of the third and the fourth epochs are -0.0007m and -0.0006m, the fourth and the fifth are 0.0002m and 0.0004m and those of the fifth and the sixth epochs are 0.0008m and 0.0006m respectively. Also the maximum differences between the first and the sixth epochs observations in northing and easting are respectively -0.0009m and 0.0008m. It can also be seen that the maximum differences between the observations epochs are all less than 1mm. Since the maximum differences between the observations epochs are all less than 1mm and the standard deviation of unit weight for the weighted observations (σ_o) of each epoch observation is less than 1cm, hence the bridge did not undergo any displacement/movement within the monitoring period. The differences between the coordinates of successive epochs of observations were as a result of centering error

Table 1: Comparison between the Consecutive Adjusted Epochs Observations

STATION ID		DIFF. B/W 1^{ST} & 2^{ND} OBSERV. EPOCHS (m)	DIFF. B/W 2^{ND} & 3^{RD} OBSERV. EPOCHS (m)	DIFF. B/W 3^{RD} & 4^{TH} OBSERV. EPOCHS (m)	DIFF. B/W & 4^{TH} 5^{TH} OBSERV. EPOCHS (m)	DIFF. B/W & 5^{TH} 6^{TH} OBSERV. EPOCHS (m)	DIFF. B/W 1^{ST} & 6^{TH} OBSERV. EPOCHS (m)
R_1 (A)	N_A	-0.0007	-0.0001	0.0001	-0.0003	0.0005	-0.0005
	E_A	0.0001	0.0004	-0.0003	0.0004	0.0000	0.0006
R_2 (B)	N_B	-0.0008	-0.0001	0.0005	-0.0001	0.0004	-0.0001
	E_B	0.0007	0.0002	-0.0006	-0.0004	0.0007	0.0006
R_3 (C)	N_C	0.0002	-0.0004	-0.0002	0.0002	-0.0001	-0.0003
	E_C	0.0004	-0.0002	0.0000	-0.0002	0.0006	0.0006
L_3(D)	N_D	0.0002	0.0002	-0.0007	0.0002	-0.0003	-0.0004
	E_D	0.0000	0.0001	0.0000	0.0004	0.0003	0.0008
L_2(E)	N_E	-0.0004	0.0003	-0.0003	-0.0001	0.0008	0.0003
	E_E	0.0004	-0.0003	-0.0001	0.0000	0.0000	0.0000
L_1 (F)	N_F	-0.0006	-0.0001	-0.0004	0.0001	0.0001	-0.0009
	E_F	0.0008	-0.0004	0.0001	-0.0003	0.0000	0.0002

3 CONCLUSION

The monitoring of Ikpoba River Bridge was carried out using GPS method; seven points were used altogether, one reference station and six monitoring stations. The coordinates of the points were determined using CHC 900 dual frequency GNSS receivers in Post Processing Static Mode. The GPS data were processed and adjusted using the Compass Post Processing software.

The processed coordinates were adjusted using least squares adjustment method. The weight of each epoch observation was computed by finding the reciprocal of the variances obtained from the variance covariance matrix of the processed GPS observations using Compass software. A design matrix of 28 ×12, matrix of unknown of 12 × 1 and residual matrix of 28 × 1 were used for the adjustment. The maximum residual of each observation epoch was computed. The standard deviation of unit weight (a posteriori standard error) for the weighted observations (σ_o) was computed for each epoch observations.

The processed and adjusted coordinates were compared consecutively by finding the difference between successive epoch observations. Also, the difference between the first and the sixth epoch observations was computed as seen in Table 1. From the comparison, it was observed that the maximum differences in coordinates of successive epoch observations were all less than 1mm; hence the bridge did not undergo any displacement/movement within the monitoring period. The differences between the coordinates of successive observations were as a result of centering error.

Ordinarily, six months period is deemed too short to detect any change but the process and analysis have been developed or established. Also, the monitoring and collection of data are still going on. It is expected that future analysis of over 12 months and 18 months periods would likely see a change may be.

4. RECOMMENDATIONS

Having monitored Ikpoba River Bridge and carried out some analysis based on the observations taken, the following recommendations are made:

1. That the monitoring interval or regularity of the ongoing survey of the bridge should not be less than six months so as to obtain any appreciable displacement/movement of the bridge.
2. That the ongoing observation on the bridge should also be analyzed using other appropriate adjustment model.

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