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Establishment of a geodetic network for deformation monitoring of the third mainland bridge, Lagos Nigeria

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ABSTRACT

There have been several cases of bridge collapse all over the world leading to loss of lives and valuable infrastructure. Such incidents can be averted if bridges are properly monitored through deformation surveys. This study aims at establishing a geodetic network for deformation monitoring of the Third Mainland Bridge in Lagos State, Nigeria. High precision Global Navigation Satellite System (GNSS) surveys were deployed for the observation. Points in the network were established by simultaneous redundant observation from three existing first order controls (XST series) in static mode. The raw field data was subjected to least squares adjustment and the redundant observations were reduced to give the three-dimensional (3D) coordinates of the points that make up the network. With this network in place, the positional integrity of the bridge can be continuously monitored.

1. Introduction

The provision and maintenance of a secure and reliable highway network is a constant challenge for transportation authorities. Bridges are not only an essential component of the network, but they are also expensive investments. To protect this investment, transportation authorities must fully comprehend the condition and actions of bridge systems in order for the bridge to remain accessible to traffic, weather-resistant, and unperturbed by millions of loadings cycles each year – all while incurring minimal maintenance costs (Van Cranenbroeck, 2007). High cost of maintenance compounded with budget-driven policies often contributes to the postponement of routine bridge repairs. These lapses can lead to the occurrence of a bridge collapse, which is unacceptably dangerous.

The Third Mainland bridge has had haphazard repairs since its inception. The Nigerian Federal Government announced in August 2018 that the bridge will be temporarily closed for four days to allow for investigative maintenance testing. The government declared in July 2020 that the bridge will be closed for six months to begin repair works. Construction was to take place in two stages, with each carriageway taking three months to complete. As part of ongoing reconstruction work, the Federal Government declared in early January that the Lagos Island-bound traffic on the Third Mainland Bridge would be closed for two weeks beginning on Wednesday, January 13, 2021 (Construction Review Online, 2021).

There are several methods for monitoring the structural integrity of bridges to prevent or reduce hazards such as bridge deformation, bridge failures or collapses. For decades, Surveyors, Geodesists and Engineers have relied on the establishment of geodetic control networks for bridge monitoring. Having multiple control stations in the reference network is critical for improving the reliability of deformation surveys, and for investigating the stability of reference monuments over time (Alademomi et al., 2020).

Given the foregoing, this study aims to establish a geodetic control network for the deformation monitoring of the Third Mainland Bridge in Lagos State Nigeria. Following established procedures, the geodetic network was designed. The three-dimensional coordinates (3D) of the reference stations and monitoring stations were determined using differential Global Navigation Satellite System (GNSS) surveys.

The establishment of such a network is imperative in the setting up of a structural health monitoring (SHM) scheme for the bridge. The findings of this study can facilitate the attainment of sustainable development goal (SDGs) No. 9 (Industry, Innovation and Infrastructure) and No. 11 (Sustainable cities and communities) in Nigeria and Africa.

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2. Methods

2.1. Study area

The Third Mainland Bridge is the longest of three bridges connecting Lagos Island to the mainland; the others are the Carter Bridge and the Eko Bridge. The Third Mainland Bridge was the longest bridge in Africa until 1996 when the 6th October Bridge located in Cairo was completed. The former starts from Oworonshoki which is linked to the Apapa-Oshodi expressway and Lagos-Ibadan expressway, and ends at the Adeniji Adele Interchange on Lagos Island. The bridge was built by Julius Berger Nigeria PLC. The phase one of the project was commissioned by President Shehu Shagari in 1980 and completed by President Ibrahim Babangida in 1990; it measures about 11.8 km in length (Construction Review Online, 2020; The Guardian News, 2020).

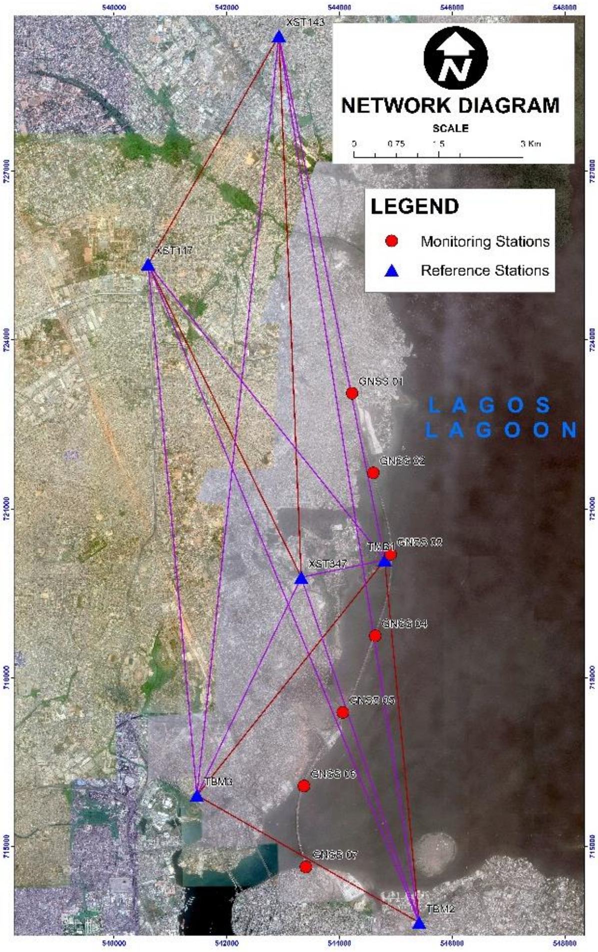

Figure 1. Network Diagram

2.2. Project planning and network design

A preliminary reconnaissance was done with the aid of Google Earth (GE) imagery and site visits. Analysis of the GE imagery enabled a holistic perspective of the survey area and provided insights such as: possible locations for establishment/monumentation of reference stations and monitoring stations, and approximate spacing between monitoring stations. Additional insights were gained during site visits such as: suitable times for field observations, stability of proposed monumentation locations, and likely human and vehicular interferences.

The network was designed with a good geometry, near-uniform spacing between monitoring stations (approx. 1.5km), well distributed reference stations and monitoring stations which span the entire length of the bridge.

2.3. GNSS observation

The 3D coordinates of the reference stations and monitoring stations were determined using 10 GPS dual frequency differential Global Positioning System (GPS) receivers and accessories. The observation was done using the following GPS equipment: UniStrong G970II Pro and Stonex S900A. The control points were referenced to Minna datum (UTM Zone 31N).

Three first order control points - XST347, XST143, and XST117 (Table 1) established by the Office of the Surveyor General, Lagos State were used as the starting points for coordination of the reference stations and monitoring stations. The UTM coordinates of the reference stations (TMB01, TMB02, and TMB03) were determined by taking simultaneous observations relative to the 1st order controls in static mode with an occupation time of 2 hours for each station. Subsequently, simultaneous observations were carried out on the monitoring stations. Three differential GPS were set on the reference stations and seven on the monitoring stations. Observations were taken for a period of one hour in static mode at each monitoring station to form the deformation monitoring baseline data.

Table 1. Coordinates of the Stations

Station	Eastıng (m)	Northing (m)	Height
XST 117	538760.513	725413.102	29.079
XST 143	542923.610	729471.575	13.072
XST 347	543241.676	719895.816	4.701

2.4 Data processing and network adjustment

The Trimble Business Centre software environment was used to post-process the GNSS data. The coordinate system of the post-processing operation was set to UTM 31N based on the WGS84 ellipsoid. For the baseline processing of the observation set, the existing coordinates of the base station were keyed in, and the post-processed coordinates were generated as the software was configured to repeatedly compute the baselines in the network.

After the adjustment, the results were subjected to statistical testing using the Trimble Business Centre. This was accomplished by comparing the observation's a priori standard deviation against its residual using a goodness-of-fit ($\chi 2$). Other tests include: blunder detection, variance of the unit weight, quality assurance test, repeated vector analysis test, tau test and observation residuals test. The goodness-of-fit test results for control network and monitoring points on the right and left of the bridge, respectively appear to follow the normal distribution and the sizes of their residuals indicated that the data appear to be consistent. The blunder was used to detect problems associated with the adjustment. The tools assist in determining if blunders exist in any of the observations used in the adjustment, or if any problems exist in the network construction that would hamper the ability for an adjustment to be performed. The results in both the establishment of the control points and monitoring station on the bridge indicated that the observations were free of blunders.

For proper adjustment of an entire dataset of observations, the connectivity between all sections of the dataset was made and the results determined that there were no subsets of the data set that are not connected by observations. The Variance of Unit Weight and the Standard Error of Unit Weight monitored the relationship between the uncertainties assigned with the observations and the magnitude of the change required to each observation (residuals) in the adjustment. Changes to the observations were small and were significantly greater than the uncertainties associated with the observations. The Variance of Unit Weight and Standard Error of Unit Weight gauged the magnitude of the observation changes (residuals) compared to the observation uncertainties for the entire network. Analyzing the magnitude of the computed Variance of Unit Weight and Standard Error of Unit Weight revealed that the changes to the observations (residuals)were within expected levels.

In the least-squares adjustment, small corrections were applied to the observations to obtain the best fit of all observations producing one solution for all points. These results indicated that the results were free of blunders because in both cases the residuals were small and even negligible in some cases. In addition, the resulting differences between repeat observations were compared to the user-defined accuracy specification. The results for all campaigns portrayed that difference between the repeated observations of a vector were smaller than the allowable error computed from the accuracy specification. The achievable accuracy in GPS measurements for deformation monitoring is between 0.1 – 2 ppm (part per million).

3. Results

The results of the processed observations are shown in Table 1 and Table 2. Table 1 shows the 3D coordinates of the reference ponts. Table 2 shows the 3D coordinates of the monitoring stations.

Figure 1 shows the final network diagram obtained from Trimble Business Centre showing the connectivity from each of the reference stations to the monitoring stations.

Table 2. Coordinates of the reference stations

Station	Easting (mE)	Northing (mN)	Height (m)
TMB1	544802.127	720089.740	1.526
TMB2	545414.493	713648.646	2.399
TMB3	541469.552	715908.690	1.910

Table 3. Coordinates of monitoring stations

Station	Easting (mE)	Northing (mN)	Height (m)
GNSS1	544217.625	723064.482	4.372
GNSS2	544692.683	721336.426	7.019
GNSS3	544899.132	720194.732	6.417
GNSS4	544235.308	717681.752	1.012
GNSS5	544064.787	717413.401	1.879
GNSS6	543431.590	716241.792	3.285
GNSS7	543408.300	714638.715	2.421

4. Discussion

This monitoring baseline is such that the subsequent epochs observations will be compared with them to ascertain any displacement. Following the determination of the coordinates, the equation that can be adopted for calculating deformation is given by Handayani and Taufik (2015):

$$dp = r'p - rp = dp(Xp, Yp, Zp; t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where;

rp = position of particle p at time $t = 0$ (before deformation);

in this study expressed as the mean position,

r'p = position after deformation at $t > 0$

5. Conclusion

In this study, we established a geodetic network for deformation monitoring of the Third Mainland Bridge. The reference and monitoring stations can be used to assess the bridge's deformation for the first epoch which is expected to take place in 2021. An active monitoring scheme should be set up for the Third mainland bridge to ensure its structural integrity and serve as an early warning system so that catastrophic loss of life and infrastructure due to bridge collapse, which could have been avoided if a monitoring system was put in place would not occur.

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