IMPACT: International Journal of Research in
Engineering & Technology (IMPACT: IJRET)
ISSN(P): 2347-4599; ISSN(E): 2321-8843
Vol. 5, Issue 8, Aug 2017, 41-50
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ESTABLISHMENT OF GEODETIC CONTROLS NETWORK FOR MONITORING OF JIMETA BRIDGE

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ABSTRACT

Bridges and flood control structures are subject to external forces that cause deformation of the structure itself, as well as its foundations. This is as a result of deflection in horizontal axis of the structure and/or settlement in vertical direction. Any indication of abnormal behavior, may threaten the safety of the structure. The need for establishing Geodetic Control Network for bridge deformation monitoring was addressed in this research. A Global Positioning System (GPS) receiver with the capabilities of accurate long-term monitoring was used. The designed scheme, therefore, involved the establishment of the geodetic control network within the study area and monuments on the bridge itself, as well as the sets of observations and adjustments using least squares as standard goal data for deformation monitoring. It also includes the observation procedure, analysis method, mathematical and statistical models for initial deformation monitoring on which subsequent deformation monitoring of the bridge will be based. The results of established monitoring network obtained determined the vector of structural deformation of Jimeta Bridge.

KEYWORDS: Control Network, Deformation, Global Positioning System,

INTRODUCTION

In general, bridge and other flood control structures are subject to external forces that cause deformation and permeation of the structure itself as well as its foundations. This is as a result of deflection in horizontal axis of the structure and/or settlement in vertical direction. Any indication of abnormal behavior, may threaten the safety of the structure. Therefore, careful monitoring of the external forces on a structure and its response to them can aid in determining abnormal behavior of that structure. To monitor these movements there is need of better control network (Steward and Tsakiri 2002; Amiri-Simooei et al. 2012).

A geodetic control network is the wire-frame, on which continuous and consistent mapping, Geographic Information Systems (GIS), and surveys are based (Ono et al. 2000). To understand the function of geodetic control, we have to realize that a map or a plan survey is a flat representation of the curved world. If we want the maps to become an authentic representation of the real world, we have to be able to "paste" small pieces of flat map contents onto a curved world. The Geodetic Control is the mechanism that enables us to perform this "pasting" seamlessly, accurately and consistently.

Traditionally, geodetic control points are established as permanent physical monuments placed in the ground and precisely marked, located, and documented. Locating spatial features with respect to geodetic control enables the accurate assessment of these features. Interest and activity regarding geodetic control have dramatically increased, because of the need for accurate maps and surveys used in geographic and land information systems. Control surveys are used to support project control densification, structural deformation studies, photo geometry, dynamic positioning and navigation for hydrographic survey vessels and dredges, hydraulic study/survey location, river/floodplain cross-section location, core drilling location, environmental studies, level overbank surveys, level profiling, level grading, disposal area construction, grade control, support for real estate surveys and regulatory enforcement actions.

GPS survey techniques can often be used to establish or density project controls more efficiently like 0020 the conventional control surveying techniques. Quality control statistics and redundant measurements in GPS networks help to ensure reliable results. Field operations to perform a GPS survey are relatively easy and can generally be performed by one person per receiver, with two or more receivers required to transfer control. GPS does not require inter-visibility between adjacent stations. Geodetic control densification can be achieved by both conventional and GPS surveying methods for a high-order geodetic control densification (Beutler et al 1988). First, second or third order control densification can be achieved by any of the two methods. Orthometric heights and conventional leveling methods can be used to determine elevations for vertical control densification.

Deformation monitoring systems may need to be capable of measuring either long term movement trends or short-term loading deformations. In this research, long-term measurements would be considered because; they are far more common and somewhat more complex. Long-term monitoring of a structure's movement typically requires observations to monitor points on the structure from external reference points. These external reference points are established on stable ground. These external reference points are interconnected and are termed the "Reference Network." The reference network must also be monitored at less frequent intervals to ensure these reference points have not themselves moved.

Monitoring, on the other hand is the determination of movements of a structure obtained by referring those movements to a network of control points outside the structure (John 2015). However, this method is not the only means of monitoring, other techniques can measure the relative movement with greater accuracy as well. The size of the structure will determine the size of the network points around it. A guideline is that a network must form a square shape around the structure with its sides, approximately the length of the structure monitored as shown in the figure below figure below (figure 1)

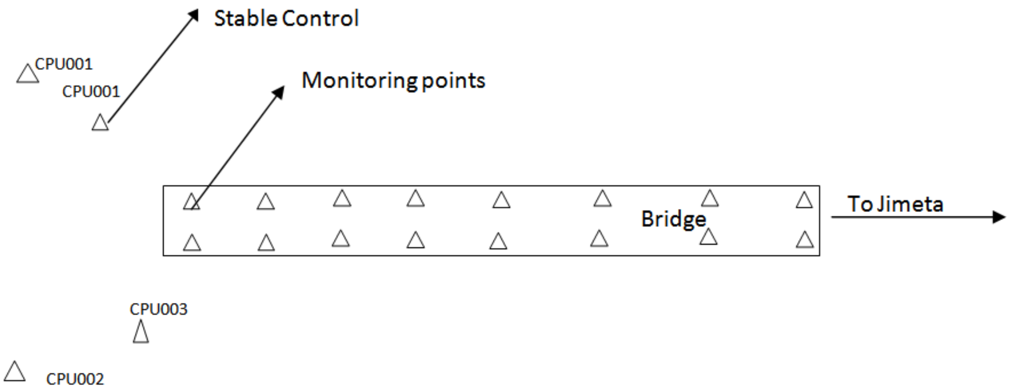

Figure 1: Network of Monitoring Control Points

STATEMENT OF PROBLEM

Bridge and other flood control structures are subject to external loads that cause deformation and permeation of the structure as well as its foundations. Any indication of abnormal behavior, may threaten the safety of the structure which will result in loss of lives and property. Most of these structures like Jimeta Bridge are not monitored, simply because, there are no bases or reference networks with which the monitoring will be carrying out. Jimeta Bridge has been in existence for many decades and many external forces have been acted upon it yet no single attempt of monitoring was performed to know its state of stability. Some monitoring is carried out using the offset method of oscillation observation and this will not portray the exact movement. Again in some monitoring process, only simple geometric analyses are applied and this will not yield a precise prediction of the movement of the structure. Also, careful monitoring of the loads on a structure and its response to them can aid in determining abnormal behavior of that structure. In this research, the triangulation networking using GPS incorporated with geometric analysis with rigorous adjustment and statistical analysis was carryout to set a base for the true and accurate determination of movement of the structure in horizontal and vertical directions.

SCOPE OF THE STUDY

This research, the geodetic triangulation control network around Jimeta Bridge with GPS monitoring survey operations was established. Surveying requirements for accuracy, system performance, and equipment is of geodetic requirement. Surveying procedures and specifications for planning, fieldwork, and data collection were covered. Data processing procedures which describe the software and processing requirements for baselines and networks, including least squares adjustment and formulation of mathematical models were taken into consideration. GPS monitoring applications was also included in the planning being a criteria for the establishment of GPS monitoring networks (Beutler et al. 1988). Also, included are procedures for performing reference network surveys that are conducted for separate high accuracy positioning tasks, and production surveys configured to follow conventional survey procedures and layouts. In addition, this research also presents results of field tests conducted to evaluate GPS surveying capabilities on monitoring networks which may serve as a base for subsequent monitoring.

STUDY AREA

The study area is Jimeta Bridge, which is a linear figure about 1.2km long located on longitude 9.2974E and latitude 12.47216N.The Bridge has been built across the river Benue at entry of Jimeta from Mubi town in Adamawa state Nigeria. The river is approximately 1,400 kilometers long and is almost entirely navigable during the summer months. As a result, it is an important transportation route in the regions through which it flows. It rises in the Adamawa Plateau of northern Cameroon, from where it flows west, and through the town of Garoua and Lagdo Reservoir, into Nigeria south of the Mandara mountains, and through Jimeta, Ibi and Makurdi before meeting the River Niger at Lokoja. Large tributaries are the Gongola River and the Mayo Kébbi, which connects it with the Logone River during floods. Other tributaries are Taraba River and River Katsina Ala.

METHODOLOGY

Data Acquisition

The data for the research were acquired with the use of the following instruments and equipments

- Dual frequency GPS and it accessories
- Kern GRI- A leveling instrument and Staff

Data Quality

A major task for meeting accuracy requirements on GPS deformation monitoring surveys is to obtain high quality data and to eliminate or minimize low quality data whenever possible. Using a constellation of satellites and radio waves, the position of a fixed pin on the flank of the bridge was measured to within a few millimeters in just a few minutes. The data was collected using GPS and ground deformation monitoring. Using Global Positioning System (GPS) techniques has the advantage of self reliance data and does not required inter-visibility. The differential mode of observation with one hour time elapse, which considerably portrays a geodetic standard of the data required for deformation monitoring. The data has been processed using GNSS solution, which also improved the quality, as the software automatically detects blunders and adjusted the results. Moreover, rigorous geodetic observation technique and quality control protocols were adhered to for adjusting the data. All monitoring points were observed in multiple pre-selected numbers. The sets were combined using rigorous least squares station adjustment, followed by data reduction algorithms employing least squares adjustments to screen blunders from the data set**.** With this, the quality of data was considered very high for this study.

Method of Data Collection

Basically in this research, GPS was used to carry out observation on remote stable monuments serving as the control network and the arrays of selected monitoring points on the Bridge to serve as the monitoring points. These stations form a triangulation network, where the baselines between the monitoring points are formulated to monitor differential movement.

Design of Measurements Schemes

The static mode was used to observe both control networks on the stable ground and the monitoring stations on the bridge. For the Control Points, one of the receivers (base) remains stationary on the control station and all the necessary settings were made. The rover was set on the control point (PCU 001). The time elapse was set to one hour and the coordinates, height and other parameters were recorded and saved automatically by the receiver. The same processes were repeated on PCU 002, PCU 003 and PCU 004, respectively with the base on M03.

The four control points established serving, as the stable control points were used for Deformation Monitoring of Jimeta Bridge. The same static mode was used for the observation on the monitoring points. One of the receivers (base) remains stationary on the control station (PCU004) and the rover was used to observe monitoring station on the bridge. The time elapse of 30 minute was used for observing each station. Pair of observations was made on the abutment (from east) of the bridge and selected piers (4, 8, 12, 16, 20, 24, and 28) on the bridge. That is eight observations on each length.

Data Processing

The data obtained from the field using GPS observation for both control network and monitoring stations were processed using GNSS Solutions. GNSS Solutions was used offers high standards of performance, processing speed, compactness and flexibility. GNSS Solutions provides accurately determined final result using software, which is based on least squares solution. Least squares adjustment was used at two different stages in processing GPS carrier-phase measurements. First, it is applied in the adjustment that yields baseline components between stations from the redundant carrier-phase observations and secondly, it is employed in processing GPS observations for adjusting baseline vector components in the network. In network adjustments, the goal is to make all X coordinates and all X-coordinate differences consistent throughout the figure. The same objective applied for all Y and Z coordinates (Lutes et al 2001).The adjustment employs the use of observation equations to relate station coordinates to the coordinate differences and their residual errors. The observation equations were written for each baseline component observed as:

$$X_C = X_A + \Delta X_{AC} + V_{XAC} \qquad 1a$$

$$Y_C = Y_A + \Delta Y_{AC} + V_{YAC} \qquad 1b$$

$$Z_C = Z_A + \Delta Z_{AC} + V_{ZAC} \qquad 1c$$

Similarly, the observation equations for the baseline components of line CD were

$$X_D = X_C + \Delta X_{CD} + V_{XCD} \qquad 2a$$

$$Y_D = Y_C + \Delta Y_{CD} + V_{YCD} \qquad 2b$$

$$Z_D = Z_C + \Delta Z_{CD} + V_{ZCD} \qquad 2c$$

The observation equation is expressed in matrix form as;

$$AX + L = V \qquad 3$$

Not all surveying data will be collected with the same level of precision. Therefore, the measurements were weighted relative to each other according to their different precisions. Weights were based on a standard deviation prescribed to each measurement, and these were calculated as the inverse of the measurement variance as follows:

$$w_i = 1 / \sigma_i^2; \qquad 4$$

Where

w_i = observation weight value

σ_i = measurement standard deviation

Error Propagation

Formulas for propagation of variances as presented in Charles and Wolf 2006, assume that standard deviations of observations are small enough to be approximated by the squared differential changes of the observables

$\sigma_x^2 = \partial x\, \partial x$, and covariance by their products

$\sigma_{xy} = \partial x\, \partial y$

For a function x (a, b) of observations a and b, the squared differential of the function x is

$$(\partial x)^2 = (\partial x/\partial a)^2\ \partial a^{\,2} + (\partial x/\partial b)^2\ \partial b + 2(\partial x/\partial a)\ \partial x/\partial b)\ \partial a\ \partial b$$

This may be generalized to any number of observables. For another function y (a, b) of the same observables a and b, the differentials of the functions x and y are

$$\partial x = (\partial x/\partial a))\ \partial a\ (\partial x/\partial b)\ \partial b$$

$$\partial y = (\partial x/\partial a)\ \partial a + (\partial x/\partial b)\ \partial b$$

Which are multiplied to calculate the covariance ∂x ∂y.

$$\partial x\ \partial y=(\partial x/\partial a)(\partial y/\partial a)da^2+(\partial x/\partial b)(\partial y/\partial b)^2\ \partial b^{\,2}+[(\partial x/\partial a)(\partial y/\partial b)+(\partial x/\partial b)(\partial y/\partial a)]\partial a\ \partial b$$

Substitution of standard deviations of a and b for the differentials gives the following error propagation result in x:

$$\sigma_x^2 = (\partial x/\partial a)^2\ \sigma_a^2 + (\partial x/\partial b)^2\ \sigma_b^2 + 2\ (\partial x/\partial a)(\partial x/\partial b)\ \sigma_{ab}$$

And in the case of uncorrelated measurements, the variances and covariance in x and y is

$$\sigma_x^2= (\partial x/\partial a)^2\ \sigma_a^2 + (\partial x/\partial b)^{\,2}\ \sigma_b^2$$

$$\sigma_y^2 = (\partial y/\partial a)^2\ \sigma_a^2 + (\partial y/\partial b)^2\ \sigma_b^2$$

$$\sigma_{xy}= (\partial x/\partial a)(\partial y/\partial a)\ \sigma_a^2 + \partial x/\partial b)(\partial y/\partial b)\ \sigma_b^2$$

Error propagation formulas are used to calculate a standard deviation for each measurement in the adjustment. Before the network adjustment process is completed, the probable error in positioning was computed for each point. Entries of the covariance matrix of parameters contain the position accuracy information. The geometric representations of the entries in the covariance matrix of parameters are through error ellipses describing the boundary of probable error around each point position. The maximum uncertainty in position is equivalent to the magnitude of the major semi-axis of this ellipse for a given probability level used for reporting results. Its orientation and shape are also determined from the numerical entries of the covariance matrix of parameters.

RESULTS AND DISCUSSIONS

The result of control network is shown in table 1. It consists of four control stations CPU001, CPU002, CPU003 and CPU004 established on a stable ground around the bridge. The second aspect of the result is the monitoring stations established on the right and left parts of the bridge; these are represented in table 2 and 3, respectively. Tables 4, 5 and 6 are the analysis of the control and monitoring networks.

Table 1: Adjusted Rectangular Coordinate of the Control Points

Name	Descriptin	Long	Lat	Ellips height	Status	Constraints	Surv_ Horz Conf	Surv_ Height Conf	Type	Warnig
BASE	STE	1382499.781	1059139.291	225.091	Adjusted	H & V Fixed(3D)	0	0	Control Point	No
CPU01	NFC	1381600.305	1053547.453	234.573	Adjusted	No constraints	0.014	0.011	Logged Point	No
CPU02	GAT	1380729.448	1053539.027	239.372	Adjusted	No constraints	0.035	0.025	Logged Point	No
CPU03	FPL	1380170.600	1053115.281	188.265	Adjusted	No constraints	0.039	0.026	Logged Point	No
CPU04	FPR	1380965.427	1052977.802	201.552	Adjusted	No constraints	0.037	0.027	Logged Point	No

Table 2: Adjusted Rectangular Coordinates of the Monitoring Points (Left)

Name	Description	East	North	Ellips height	Status	Constraints	Surv Horz Conf	Surv Heigt Conf	Type	Warnig
CP004	FPMR	1380970.581	1052979.072	203.049	Adjusted	No constraints	0.094	0.062	Logged Point	No
TP09	P028	1379834.130	1051625.548	192.270	Adjusted	No constraints	0.275	0.158	Logged Point	No
TP10	P024	1379962.300	1051780.267	199.319	Adjusted	No constraints	0.232	0.164	Logged Point	No
TP11	P020	1380090.533	1051935.079	200.304	Adjusted	No constraints	0.194	0.163	Logged Point	No
CP12	P016	1380218.799	1052089.807	197.949	Adjusted	No constraints	0.184	0.128	Logged Point	No
TP13	P012	1380347.062	1052244.631	195.588	Adjusted	No constraints	0.163	0.116	Logged Point	No
TP14	P008	1380475.410	1052399.504	193.255	Adjusted	H. & V. Fixed (3D)	0	0	Control Point	No
TP15	P004	1380603.640	1052554.341	190.882	Adjusted	No constraints	0.172	0.106	Logged Point	No
TP16	AB00	1380731.504	1052708.629	188.552	Adjusted	No constraints	0.175	0.103	Logged Point	No

Table 3: Adjusted Rectangular Coordinate of the Monitoring Points (Right of the Bridge)

Name	Description	East	North	Ellipse height	Status	Constraints	Surv_Horz _Conf	Surv_ Height _Conf	Type	Warning
PC04	FPMR	1380965.561	1052978.856	199.906	Adjusted	H&V Fixed (3D)	0	0	Control Point	No
TP01	AB00	1380714.214	1052718.417	185.431	Adjusted	No constraints	0.011	0.006	Logged Point	No
TP02	P004	1380586.372	1052564.168	187.72	Adjusted	No constraints	0.01	0.007	Logged Point	No
TP03	P008	1380458.238	1052409.42	190.024	Adjusted	No constraints	0.01	0.007	Logged Point	No
TP04	P012	1380329.889	1052254.43	192.477	Adjusted	No constraints	0.011	0.007	Logged Point	No
TP05	P016	1380201.655	1052099.578	194.809	Adjusted	No constraints	0.013	0.007	Logged Point	No
TP06	P020	1380073.401	1051944.745	197.061	Adjusted	No constraints	0.013	0.01	Logged Point	No
TP07	P024	1379944.878	1051789.872	196.058	Adjusted	No constraints	0.01	0.008	Logged Point	No
TP08	P028	1379816.701	1051635.113	189.049	Adjusted	No constraints	0.018	0.013	Logged Point	No

Table 4: Analysis of the Control Network

Reference	Rover	Adj._Q.A	Tau_Test	Adj. Length	Length Residual	Adjusted DX	DX Residual	Adjusted DY	DY Residual	Adjusted DZ	DZ Residual
BASE	CPU04	No	Yes	6202.85	0	1291.006	0	-1469.47	0	-5886.37	0
BASE	CPU03	No	Yes	6309.434	0	1419.179	0	-2230.94	0	-5728.68	0
BASE	CPU02	No	Yes	5737.636	0	1285.2	0	-1686.64	0	-5331.42	0
BASE	CPU01	Yes	Yes	5532.69	0.01	1100.342	-0.008	-856.478	-0.005	-5354.1	-0.005
BASE	CPU01	Yes	Yes	5532.69	0.047	1100.342	0.043	-856.478	0.008	-5354.1	0.018
BASE	CPU01	Yes	Yes	5532.69	0.012	1100.342	-0.005	-856.478	-0.006	-5354.1	-0.009
BASE	CPU01	Yes	Yes	5532.69	0.192	1100.342	0.148	-856.478	0.086	-5354.1	0.086
BASE	CPU01	Yes	Yes	5532.69	0.213	1100.342	0.167	-856.478	0.102	-5354.1	0.083
BASE	CPU01	Yes	Yes	5532.69	0.191	1100.342	0.148	-856.478	0.088	-5354.1	0.083
BASE	CPU01	Yes	Yes	5532.69	0.199	1100.342	0.157	-856.478	0.092	-5354.1	0.08
BASE	CPU01	Yes	Yes	5532.69	0.208	1100.342	0.17	-856.478	0.09	-5354.1	0.08
BASE	CPU01	Yes	Yes	5532.69	0.006	1100.342	-0.003	-856.478	-0.004	-5354.1	-0.003
BASE	CPU01	Yes	Yes	5532.69	0.078	1100.342	0.044	-856.478	0.062	-5354.1	-0.016
BASE	CPU01	Yes	Yes	5532.69	0.078	1100.342	0.044	-856.478	0.062	-5354.1	-0.016
BASE	CPU01	Yes	Yes	5532.69	0.006	1100.342	-0.003	-856.478	-0.004	-5354.1	-0.003
BASE	CPU01	Yes	Yes	5532.69	0.078	1100.342	0.044	-856.478	0.062	-5354.1	-0.016
BASE	CPU01	Yes	Yes	5532.69	0.006	1100.342	-0.003	-856.478	-0.004	-5354.1	-0.003

Table 5: Analysis of the Monitoring Points (Right)

Reference	Rover	Adj_QA	Tau_Test	Adjusted Length	Length Residual	Adjusted DX	DX Residual	Adjusted DY	DY Residual	Adj_DZ	DZ Residual
PC04	TP01	Yes	Yes	353.88	0	79.744	0	-242.987	0	-244.6	0
PC04	TP07	Yes	Yes	1530.826	0.007	397.855	-0.005	-975.054	-0.002	-1111.039	-0.004
PC04	TP07	Yes	Yes	1530.826	0.003	397.855	-0.001	-975.054	-0.001	-1111.039	-0.002
PC04	TP07	Yes	Yes	1530.826	0.023	397.855	0.022	-975.054	0.006	-1111.039	0.004
PC04	TP06	Yes	Yes	1334.243	0	347.443	0	-852.162	0	-966.078	0
PC04	TP05	Yes	Yes	1137.883	0	293.951	0	-730.222	0	-821.674	0
PC04	TP04	Yes	Yes	941.553	0	240.378	0	-608.319	0	-677.266	0
PC04	TP03	Yes	Yes	745.102	0	186.636	0	-486.333	0	-532.751	0
PC04	TP02	Yes	Yes	549.074	0	133.115	0	-364.522	0	-388.44	0
PC04	TP08	Yes	Yes	1727.138	0	442.384	0	-1098.9	0	-1256.874	0

Table 6: Analysis of the Monitoring Points (Left)

Reference	Rover	Adj_QA	Tau_Test	Adjusted Length	Length Residual	Adjusted DX	DX Residual	Adjusted DY	DY Residual	Adjusted DZ	DZ Residual
BASE	TP09	No	Yes	1726.591	0	441.493	0	-1087.03	0	-1266.71	0
BASE	CP05	No	Yes	548.457	0	132.242	0	-352.827	0	-398.534	0
BASE	CP04	No	Yes	744.754	0.012	185.864	-0.006	-474.715	0	-542.917	-0.01
BASE	CP04	No	No	744.754	1.922	185.864	1.88	-474.715	-0.169	-542.917	0.361
BASE	CP04	No	Yes	744.754	0.172	185.864	0.118	-474.715	-0.085	-542.917	0.093
BASE	CP04	No	Yes	744.754	0.188	185.864	0.153	-474.715	-0.074	-542.917	0.082
BASE	CP04	No	Yes	744.754	0.189	185.864	0.161	-474.715	-0.069	-542.917	0.07
BASE	CP04	No	Yes	744.754	0.161	185.864	0.158	-474.715	-0.028	-542.917	0.017
BASE	CP04	No	Yes	744.754	0.163	185.864	0.16	-474.715	-0.029	-542.917	0.017
BASE	CP04	No	Yes	744.754	0.154	185.864	0.149	-474.715	-0.035	-542.917	0.019
BASE	CP04	No	Yes	744.754	0.012	185.864	0.01	-474.715	-0.005	-542.917	-0.004
BASE	CP04	No	Yes	744.754	0.004	185.864	-0.001	-474.715	-0.002	-542.917	0.004
BASE	CP13	No	Yes	941.202	0	239.471	0	-596.726	0	-687.338	0
BASE	CP12	No	Yes	1137.584	0	293.074	0	-718.65	0	-831.713	0
BASE	CP11	No	Yes	1333.91	0	346.651	0	-840.58	0	-975.999	0
BASE	CP10	No	Yes	1530.291	0	397.01	0	-963.191	0	-1120.91	0
BASE	CP06	No	Yes	352.926	0	78.821	0	-231.28	0	-254.664	0

DISCUSSIONS OF RESULTS

After the adjustment, the results were subjected to statistical testing using the GNSS solution. This was accomplished by comparing the observation's a priori standard deviation against its residual using a goodness-of-fit (χ^2)

test. 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 of the GNSS solution 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 observation were free of blunders.

For proper adjustment of an entire data set of observations, the connectivity between all sections of the data set 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 gauge 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 reveals that the changes to the observations (residuals) are within expected levels.

In the least-squares adjustment, small corrections are applied to the observations to obtain the best fit of all observations producing one solution for all points. The best fit is the solution that produces the least amount of corrections to the observations. These small corrections are termed residuals. Each observation has three residuals, one for each component of the vector (X, Y, and Z) for control network, monitoring points (right and left) respectively. These results indicated that the results were free of blunders because in both cases the residuals were small and even negligible to 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.

CONCLUSIONS AND RECOMMENDATIONS

The control network was established on the stable ground, around the bridge as well as the monitoring stations established on the selected parts of the bridge. In both cases, the positions and height of each established point were observed using Pro-mark 3 differential GPS in static mode. The time elapse of one hour was used for the establishment of control network and 30 minute was used for the observation of monitoring station. The observed data were processed using GNSS Solution soft ware. The resulting data was subjected to statistical test to ascertain its goodness of fit and network connectivity variance of the unit weight/standard error of the unit weight. The test indicates that there are no blunders detected in data. The repeated vector analysis shows that, the data had passed Tau test and quality assurance (QA) test.

It is hereby recommended that the results of this study be used for deformation analysis studies, using GPS measurements. GPS measurement technique can be used for determining of deformations, with some special precautions for eliminating GPS error sources. These include, using forced centering mechanisms to avoid centering errors, using special equipments for precision antenna height readings, using special antenna types to avoid multipath effects etc.

However, even though these precautions, to provide better results in deformation analysis, GPS measurements have to be supported with Precise Leveling measurements in vertical positioning.

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