RELIABILITY STUDY ON DAM DEFORMATION MONITORING USING GEODETIC AND OPTIMIZATION TECHNIQUE

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Abstract

Dam deformation monitoring techniques require the establishment of triangulation network within the dam area for the study of the deformation. However, in a case whereby there exist many dams and they need to be monitored simultaneously, then there is the need to take the curved nature of the earth into consideration. In this paper, marked object points on seven dams were formed into a triangulation network and computed through relevant geodetic and optimization principles. Observation equation method was used to define equations relating observations to the unknown parameters. Three control stations were used as main control stations. Thirteen curvilinear triangles are considered, consisting of twenty unknown parameters in seventy-eight geodetic observables. Geodetic optimization principles were employed in achieving necessary statistical conclusions regarding the reliability of the network. The variance covariance matrix is derived from the adjustment procedure. Necessary algorithm also produced the error ellipse data for each station. A close examination of the output indicates the stability of the object points at the examined epochs. This paper aims at determining and investigating the strength or weakness (reliability, dependability or trustworthiness) of the network of the dams' positions using geodetic and optimization techniques.

Keywords: Dams, triangulation network, deformation, variance-covariance, error ellipse, Geodetic monitoring

1.0 Introduction

The position of a point in space can be geometrically described by three-dimensional geographic and Cartesian coordinates referenced to the centre of mass of the earth. However, the introduction of the construction of an auxiliary sphere of unit radius and relating it to the ellipsoid *(Richard, 1993)* has enabled and allowed the separation of horizontal positions and vertical positions of geodetic points above the ellipsoid. While Surveyors prefer to describe positions of points in terms of their Cartesian equivalent, Geodesists prefer as appropriate and informative description of relative points in terms of latitude, longitude and ellipsoidal height. The configuration of the network of triangles would be investigated and subjected to "line-test" (whether short, medium or long lines are involved) which should hopefully lead to the usage of the right formulae (Richard, 1993).This leads to the appropriate solution of the inverse and direct geodetic problems, being the two main geometric geodetic computation problems (Krakiwsky & Thomson, 1974). Short lines are graded as lines less than or equal to 80-100km, depending on the strength of the formula. Hence, formulae, whose results are considered correct to 1 ppm at 100 km would be suitable for such geodetic computation. Lines with lengths above

80km, or ranging between 100km and 500km could be regarded as medium lines (Rapp, 1993). However, lines measuring more than 500km are long lines. The deformation of a body is fully described if the displacement field d (x,y,z; t-t_0) is known (Chen Y.Q, Chrzanowski A, et. al, 1983). The local Cartesian coordinates of points to which the observables L(t) is related are the x,y,z. The observables and deformation parameters are related through a generalized model

$$L(t) = L(t_0) + \Delta L\,(x,y,z;\ t-t_0;\ \underline{e}) \qquad \text{eq. (1)}$$

Where $\underline{e}$ is the vector of deformation parameter. However, Ali H. Fagir and Mudathir O. Ahmed (2013) worked on a procedure for detection of deformations using survey control networks using coordinates in plane geometry. Abdulkadir and Mutari (2015) also reviewed the concept of the importance and application of control network to effective monitoring of dams structures within the scope of engineering geodesy. Ehigiator, Ehiorobo et al.(2014) used a kinematic model to predict the magnitude of displacement of object points using Kalman Filter technique. Basic geometric data capture surveying instruments were used and a single dam was considered as a case study. In this paper, short and medium lines are considered, since the distances involved are mostly above 10000 km. In addition, geodetic observables will be considered instead of plane geometry.

The motivation for this research arose from the fact that Osun state Nigeria has more than fifteen dams under her control with no evidence of geodetic monitoring of any. In addition, there are about five dams that had broken down structurally. Hence, they are out of effective use. The cost of ineffectiveness of the damaged dams definitely outweighs the cost of geodetic and engineering monitoring of the dams if deformation study had been done earlier. Thus, three main first order controls are used as controls for the research. These are FGP-27, KAJOLA-1 and EDCS 01 all being statistically tested and confirmed to be homogeneous. Seven dams within the geographical enclosure of Osun state are involved in the test. They are Ede dam (EDE), Ejigbo dam (EJG), Iwo dam (IWO), Owala dam (OWL), Eko-Ende dam (EKO), Esa Odo dam (ESA), and Ilesha dam (ILS). Table 1 shows the raw data and adjusted data used as epoch one and two data in the computations and analysis in this paper. The table shows the latitude (φ) and longitude (λ) of a major object stations in each dam, which would be involved in the least squares optimization analysis. In order to know which formulae must be used in computing the direct and inverse geodetic problems in this chain, it is necessary to subject the chain to a distance test. All programs in this project are written in MATLAB environment. Table 2 gives the output of distances between every two stations within each triangle, for the thirteen triangles involved. From investigation, all lines in the chain could be regarded as short or medium lines.

2.0 Control Information

Table 1: Coordinates and Location Of All Control Points

CONTROL PILLAR	LATITUDE (Dec of Deg)	LONGITUDE (Dec of Deg)	LOCATION
FGP-027	7.795315833	4.541941944	LANDERO ROUND ABOUT, OSOGBO. [OSGOF PUBLISHED PILLAR]
EDCS-01	7.731785703	4.516058511	FRONT OF STATE SECRETARIAT ABERE [STATE PUBLISHED PILLAR]
KAJOLA	7.74678646	4.63137742	BESIDE KAJOLA NEW DAM, ILESA RD. KAJOLA[TRANSLOCATION FROM ABOVE 2 PILLARS]

All stations are within the boundary of Osun state in Nigeria. EDCS-01 and KAJOLA pillars had their coordinates established from FGP-027, published by the Office of the Surveyor General of the Federation (OSGOF) in the FGP series. The coordinates of the three pillars were checked for homogeneity. Results show an average difference of -0”.0003 in the latitude and + 0”.0004 in the longitude.

3.0 Literature, Materials, Models, Methods

In geodetic position computations, equations relating observations to the unknown parameters are defined by either observation equation method or condition equation method of solving least squares problems. In this paper, observation equation method was used, with the mathematical model

$$La = f\ (Xa) \qquad \text{eq. (2)}$$

In practice, observations made in geodetic fieldwork include, but not limited to angles (in rounds), Laplace Azimuth, distances, GPS Coordinates etc. The parameters being sought are usually the correction to coordinates ($\Delta\phi$ and $\Delta\lambda$). According to Rapp (1991), the solution of either the direct or the inverse geodetic problem is basically a solution of the ellipsoidal polar triangle (Figure 3). There are different methods for the computational solution of ellipsoidal polar triangle (Fig 3.1) to obtain geodetic coordinates (Rapp, 1987) namely Series Development in Powers of s, the Puissant Formulas, Gauss Mid Latitude Formulas, Bowring Formulas, etc. MATLAB programs (Olunlade, 2017) were used for the solution of large matrix manipulation in solving the least squares problems arising from the computation and adjustment of the dams’ geo location geometric data.

FIGURE 1: MAP OF NIGERIA SHOWING STATES

FIGURE 2: ADMINISTRATIVE MAP OF OSUN STATE

2.1 Direct Solution

The series development in powers of s **(s is the arc length between two points)**– method is used in this paper. Given the coordinates of a starting point (ϕ_1, λ_1), distance separating the geodesic (s), and Azimuth from starting point to second point (α_{12}), the problem is to find the coordinates of the second point (ϕ_2, λ_2) and the back Azimuth from second point to the starting point (α_{21}).

$\frac{\Phi 2 - \phi 1}{V^2}$ = u - $\frac{1}{2}v^2$t -$\frac{3}{2}u^2\eta^2$t - $\frac{v^2}{6}u(1+3t^2+\eta^2-9\eta^2t^2)$ - $\frac{u^3}{2}\eta^2(1-t^2)$ + $\frac{v^4}{24}t(1+3t^2+\eta^2-9\eta^2t^2)$ + $\frac{v^2u^2}{12}t(4+6t^2-13\eta^2-9\eta^2t^2)$ + $\frac{1}{2}u^4\eta^2t$ + $\frac{v^4}{120}u(1+30t^2+45t^4)$ - $\frac{v^2u^3}{30}(2+15t^2+15t^4)$ = X

$$\Phi_2 = \Phi_1 + V^2 X \qquad \text{eq (3)}$$

$(\lambda_2 - \lambda_1)$ Cos ϕ_1 = v + vut - $\frac{v^3}{3}t^2$ + $\frac{u^2}{3}v(1+3t^2+\eta^2)$ - $\frac{v^3}{3}t(1+3t^2+\eta^2)$ + $\frac{u^3}{3}v(2+3t^2+\eta^2)$ + $\frac{v^5}{15}t^2(1+3t^2)$+ $\frac{u^4}{15}v(2+15t^2+t^4)$ + $\frac{v^3}{15}u^2(1+20t^2+30t^4)$ + $\frac{v^5}{15}t^2(1+3t^2)$+ $\frac{u^4}{15}v(2+15t^2+t^4)$ + $\frac{v^3}{15}u^2(1+20t^2+30t^4)$ = Y

$$\lambda_2 = \lambda_1 + \text{Y. Sec}\,\phi_1 \qquad \text{eq(4)}$$

$\alpha_{21} - (\alpha_{12} \pm 180^o)$ = vt + $\frac{vu}{2}(1+2t^2+\eta^2)$ - $\frac{v^3}{6}t(1+2t^2+\eta^2)$ + $\frac{vu^2}{6}t(5+6t^2+\eta^2-4\eta^4)$
$\frac{v^3}{24}u(1+20t^2+24t^4+2\eta^2-8\eta^2t^2)$ + $\frac{u^3}{24}v(5+28t^2+24t^4+6\eta^2-8\eta^2t^2)$
$\frac{v^5}{120}t(1+20t^2+24t^4)$ - $v^3\frac{u^2}{120}t(58+280t^2+240t^4)$ + $\frac{vu^4}{120}t(61+180t^2+120t^4)$ = Z

$$\alpha_{21} = (\alpha_{12} \pm 180^o) + Z \qquad \text{eq(5)}$$

$V^2 = 1 + \eta^2$; c = $\frac{a^2}{b}$; v = $\frac{VsSin\alpha}{c}$; u = $\frac{VsCos\alpha}{c}$; $\eta^2 = e'^2$ Cos $^2\phi$; t = tan ϕ

Above equations are usable for lines up to 130km Bagratuni (1967) and Grushinsky (1969). All angular units of the latitude and longitude are converted to radians. The direct solution is non – iterative.

2.2 Inverse Solution

Given the coordinates of a starting point (ϕ_1, λ_1), the coordinates of the second point (ϕ_2, λ_2), the problem is to find the Azimuth from starting point to second point (α_{12}), Back Azimuth from second point to the starting point (α_{21}), and the distance separating the geodesic (s). The inverse solution is iterative.

$$\Delta\phi = \phi_2 - \phi_1; \qquad \Delta\lambda = \lambda_2 - \lambda_1$$

Before iteration, get initial values of α_{12} and s from tan $\alpha_{12} = V_1{}^2 Cos\phi_1 \left[\frac{\Delta\lambda}{\Delta\phi}\right]$, compute pre – iteration value of s from s = $\frac{c}{V_1^3}\frac{\Delta\phi}{Cos\,\alpha_{12}}$ and obtain α_{12} and s accordingly. With α_{12} and s computed, values of Δ_A and Δ_B are computed from $\phi_2 - \phi_1 = \frac{V_1^3}{c}$ Cos α_{12} . s + Δ_A

$$\Delta_A = (\phi_2 - \phi_1) - \frac{V_1^3}{c}\text{Cos}\,\alpha_{12}\ .\ s$$

$$\lambda_2 - \lambda_1 = \frac{V_1}{c} \frac{Sin\,\alpha_{12}}{Cos\,\phi_1} . s + \Delta_B$$

$$\Delta_B \quad = \quad (\lambda_2 - \lambda_1) - \frac{V_1}{c} \frac{Sin\,\alpha_{12}}{Cos\,\phi_1} . s \qquad \text{eq (6)}$$

Calculate a new α_{12} from tan α_{12} = ${V_1}^2 Cos\phi_1 \left[\frac{\Delta\lambda - \Delta_B}{\Delta\phi - \Delta_A}\right]$ and then compute a new s from s = $\frac{c}{V_1^3} \frac{\Delta\phi - \Delta_A}{Cos\,\alpha_{12}}$. Compute a new set of Δ_A and Δ_B and then repeat steps c, d, e again until the difference between successive computed values of α_{12} and s become mathematically inconsiderable. Compute Back azimuth $\alpha_{21} = \alpha_{12} \pm 180^o$

2.3 Least Squares Computational Steps

From Geodetic Positioning (Ayeni, 1980), the following mathematical model and stochastic model for observation equation method of solving least squares problems are listed (Table 3.1). Literature explains the formulation of the different mathematical models for observations in geodetic surveying (angles, distances, azimuth, GPS coordinates), leading to appropriate observation equations which would eventually yield vectors of residual. For full details of mathematical and statistic model, see (Ayeni, 1980)

$La = f(X_a)$; $X_a = X_o + X$; $V = AX + L$; $L = L^o - L^b$;
$L^o$is the L observed; L^b is the L computed
$NX = U$; $N = A^TPA$; $U = -A^TPL$; $X = N^{-1} U$ eq (7)
n – m; where n=number of observations and m=number of parameters
Variance of unit weight is $\frac{V^T PV}{n-m}$ while the co-variance matrix of adjusted parameters is $(\sum X_a)^2 = \sigma_o^2 \; N^{-1}$
The covariance matrix of adjusted observations is $\sigma_o^2 \; (AN^{-1} A^T)$.
Note that the following notation and definition remain for respective symbols:
$A = \frac{\partial f\,(X_a)}{\partial\,(X_a)}$; X = corrections to Xo; $L^o = f\,(X_o)$; $L^a = L^b + v$;
L^b = observations, Xo = approximate values of parameters;
Xa = Adjusted parameters

2.4.1 Formulation Of Design Matrix

The design matrix has been formulated using full curvilinear geometry model (2.4.1), and then subjecting the results to necessary stochastic tests to determine the correctness of usage.

2.4.2 USING ELLIPSOIDAL GEOMETRY MODEL FOR SHORT / MEDIUM LINES

In this method, the main observation equations of 2.1 to 2.7 were used to form the design matrix A. Complete curvilinear algorithm was used in the formulation of the elements of the matrix, and a program was written in MATLAB environment to compute each respective elements of the design matrix, first as A1 in 39x4 matrix and later as A matrix which is 39x20 matrix. The formulae are as follows from literature: (Rapp, 1991).

When only point 2 is free to move: Consider the change in $\phi_2, \boldsymbol{\lambda}_2$ caused by a change in distance ds and forward azimuth change $d\alpha_{12}$ at the first point P_1:

ds = $-M_2 \text{ Cos } \alpha_{21} \boldsymbol{d}\phi_{\mathbf{2}}$ $- N_2 \text{ Cos } \phi_2 \text{Sin } \alpha_{21} \boldsymbol{d\lambda_2}$

w $d\alpha_{12}$ = $M_2 \text{ Sin } \alpha_{21} \boldsymbol{d}\phi_{\mathbf{2}}$ $-N_2 \text{ Cos } \phi_2 \text{Cos} \alpha_{21} \boldsymbol{d\lambda_2}$

w $d\alpha_{21}$ = $M_2 \text{ Sin } \alpha_{21} \frac{\boldsymbol{dw}}{\boldsymbol{ds}} \boldsymbol{d}\phi_{\mathbf{2}}$ $+ N_1 \text{ Cos } \phi_1 \text{Cos} \alpha_{12} \boldsymbol{d\lambda_2}$

$$\frac{\boldsymbol{dw}}{\boldsymbol{ds}} = \boldsymbol{Cos} \frac{\boldsymbol{s}}{\boldsymbol{R}}$$

eq(8)

When Both End Points 1 & 2 are Free to Move:

ds$_T$=$-M_2 \text{ Cos } \alpha_{21} \boldsymbol{d}\phi_{\mathbf{2}}$ - $M_1 \text{ Cos } a_{12} \boldsymbol{d}\phi_{\mathbf{1}}$ - $\text{N}_2 \text{ Cos } \phi_{\mathbf{2}} \text{ Sin } \alpha_{21}(\boldsymbol{d\lambda_2} - \boldsymbol{d\lambda_1})$

w$d\alpha_{12\boldsymbol{T}}$ =$M_2 \text{ Sin } \alpha_{21} \boldsymbol{d}\phi_{\mathbf{2}} + M_1 \text{Sin} a_{12} \frac{\boldsymbol{dw}}{\boldsymbol{ds}} \boldsymbol{d}\phi_{\mathbf{1}} - \text{N}_2 \text{ Cos } \phi_{\mathbf{2}} \text{ Cos } \alpha_{21}(\boldsymbol{d\lambda_2} - \boldsymbol{d\lambda_1})$ eq(9)

For ease of computation, ellipsoid is equivalent to sphere whose radius is the GMR at the first point. Putting $M_1 = M_2 = \text{N}_2 = \text{R}$

s$d\alpha_{12\boldsymbol{T}}$ =$\text{Sin } \alpha_{12} \boldsymbol{d}\phi_{\mathbf{1}} + M_2 \text{ Sin } a_{21} \boldsymbol{d}\phi_{\mathbf{2}} - \text{N}_2 \text{ Cos } \phi_{\mathbf{2}} \text{ Cos } \alpha_{21}(\boldsymbol{d\lambda_2} - \boldsymbol{d\lambda_1})$

eq(10)

3.0 Results And Discussions

Coordinates obtained are tested for dependability before being used in the deformation analysis. Table 1 below shows output adjusted coordinates.

Table 3.1: Raw And Adjusted Data - Epoch 1, Epoch 2 & Epoch 3 Data

SERIAL NO	LATITUDE (Dec of Degrees)	LONGITUDE (Dec Of Degrees)	EPOCH	LATITUDE (Dec Of Degrees)	LONGITUDE (Dec Of Degrees)	COMMENT
	RAW	RAW		ADJUSTED	ADJUSTED	
1	7.758333333	4.458333333	1	7.756605125	4.458335164	
EDE	7.758504917	4.455136558	2	7.756459648	4.455138361	EDE
	7.757430556	4.455930556	3	7.758555723	4.455134691	
2	7.894444444	4.533333333	1	7.892713077	4.533362755	
OWALA	7.894400497	4.537152511	2	7.892351214	4.537184266	OWL
	7.892505556	4.539105556	3	7.894443111	4.537180015	
3	7.933333333	4.591666667	1	7.931604965	4.591677052	EKO
EKO	7.93730375	4.595228022	2	7.9352588	4.595239009	
ENDE	7.936252778	4.596075	3	7.937356622	4.595234526	
4	7.758333333	4.8125	1	7.75655025	4.812411374	ESA
ESA	7.757926094	4.812731061	2	7.755828084	4.812641437	
ODO	7.756844444	4.813597222	3	7.757942189	4.812659797	
5	7.866666667	4.366666667	1	7.864915669	4.366624805	EJG
EJIGBO	7.865800375	4.369438203	2	7.863733736	4.369397766	
	7.864730556	4.370241667	3	7.865833719	4.369391458	
6	7.633333333	4.2	1	7.631306573	4.199967061	IWO
IWO	7.637024603	4.199640953	2	7.634680465	4.199605456	
	7.635930556	4.200441667	3	7.636780085	4.199597820	
7	7.6	4.7125	1	7.598263473	4.712541524	ILS
ILESHA	7.601272656	4.712714961	2	7.59921952	4.712756089	
	7.601141667	4.712613889	3	7.601315678	4.712753915	
8	7.795315833	4.541941944	1	7.79359124	4.541945032	F27
FGP-	7.795315833	4.541941944	2	7.793274681	4.541946057	
027	7.795315833	4.541941944	3	7.795373560	4.541941547	
9	7.731785703	4.516058511	1	7.729945206	4.516136242	ABR
EDCS	7.731785703	4.516058511	2	7.7296283	4.51613376	
01	7.731785703	4.516058511	3	7.731726561	4.516128763	
10	7.74686333	4.63156198	1	7.746863338	4.631561984	
KAJOLA	7.74678646	4.63137742	2	7.746863596	4.631561748	KAJ-1
	7.74672384	4.63123718	3	7.746863249	4.631562248	

Table 3.2: Consistency Test On 39 Geodesics Involved In The Triangulation Net

epoch 1	epoch 2	epoch 3	δ_{12}	δ_{13}
(m)	(m)	(m)	(m)	(m)
7591.0766808	7591.0820352	7591.0819578	0.0053544	0.0052770
21911.4995030	21951.0645318	21950.9945417	39.5650288	39.4950387
20538.2323770	20560.6811140	20560.5790182	22.4487370	22.3466412
20541.1910027	20563.6589052	20563.5567977	22.4679025	22.3657950
18818.9274440	18771.1899707	18770.9591726	-47.7374734	-47.9682715
10969.9886049	10966.9008098	10966.0720774	-3.0877952	-3.9165275
20541.1910027	20563.6589052	20563.5567977	22.4679025	22.3657950
26217.0706862	26129.9795157	26129.8068936	-87.0911706	-87.2637927
16805.7911608	16761.9916220	16761.8944629	-43.7995389	-43.8966979
10969.9927614	10966.9058086	10966.0770756	-3.0869528	-3.9156858
8000.6446963	7967.7782253	7968.1707516	-32.8664710	-32.4739448
16805.7911608	16761.9916220	16761.8944629	-43.7995389	-43.8966979
16806.5098206	16762.6950491	16762.5978857	-43.8147715	-43.9119349
31028.7965190	31114.6889154	31115.1482224	85.8923964	86.3517034
30112.8435821	30144.2379855	30146.0693576	31.3944034	33.2257755
30110.2346623	30141.5986680	30143.4309291	31.3640056	33.1962668
20549.6302549	20523.3711933	20526.0303992	-26.2590617	-23.5998557
28533.0856484	28558.3978664	28558.4429235	25.3122180	25.3572751
20549.6302549	20523.3711933	20526.0303992	-26.2590617	-23.5998557
26023.3971584	26050.2088653	26050.2341152	26.8117068	26.8369568
32814.5018684	32835.7849088	32838.0188312	21.2830404	23.5169628
26017.8748988	26044.6753540	26044.7005905	26.8004553	26.8256918
56698.1777335	56758.5654029	56758.2928748	60.3876694	60.1151413
36414.6003942	36467.7036559	36467.3620829	53.1032616	52.7616887
36407.1675943	36460.2275700	36459.8862382	53.0599757	52.7186439
31389.2785173	31501.1525534	31500.8678229	111.8740361	111.5893055
21907.6843948	21947.2409216	21947.1709696	39.5565268	39.4865747
31389.2785173	31501.1525534	31500.8678229	111.8740361	111.5893055
15166.2966124	15168.1597490	15168.4720360	1.8631367	2.1754236
31212.1227650	31236.8923397	31236.6432488	24.7695747	24.5204838
15167.8195316	15169.6729337	15169.9852688	1.8534021	2.1657373
20538.2323770	20560.6811140	20560.5790182	22.4487370	22.3466412
10368.5936593	10403.6381787	10403.5072222	35.0445194	34.9135629
10369.3654681	10404.4112742	10404.2803363	35.0458061	34.9148682
7591.0766808	7591.0820352	7591.0819578	0.0053544	0.0052770
7303.3728472	7353.3746330	7353.0352620	50.0017858	49.6624148
11238.8421175	11238.8498696	11238.8498558	0.0077521	0.0077383
12837.0128947	12836.9699590	12836.9701910	-0.0429357	-0.0427037
7591.2380180	7591.2433665	7591.2432892	0.0053485	0.0052712

In testing for the dependability of obtained geodesics,
the test hypothesis used is H_0: E $\{\sigma_0^2\}$ = E $\{\hat{\sigma}_0^2\}$.
The Alternate hypothesis H_A: E $\{\sigma_0^2\} \neq$ E $\{\hat{\sigma}_0^2\}$.
The test statistic is $T_\chi = \frac{\hat{\sigma}_0^2}{\sigma_0^2}.r$

Where T_χ falls within the interval of $\chi^2{}_{S=\alpha\frac{1}{2},f=r}$ and $\chi^2{}_{S=1-\alpha\frac{1}{2},f=r}$ then the test hypothesis H_0 cannot be rejected and the test passes; otherwise, the H_A is accepted and the test fails (. α is 5%).

From Table 2, differences were computed δ_{12} between epoch 1 and epoch 2 as well as δ_{13} between epoch 1 and epoch 3. The discrepancies Δ_{123} in the differences $\Delta_{123} = \delta_{13} - \delta_{12}$ are then passed through the χ^2 test at 5% confidence level. The standard deviation computed from the discrepancies is $\hat{\sigma}_0 = 0.84570658499$ while the test statistics T_χ is 27.17834586.

Table 3.3: Percentage Of Agreement Of Variances (Epoch 1-Epoch 2) & (Epoch 1-Epoch 3)

	F-Test (1 - 2(a))	**F-Test (1 - (2b))**
EPOCH 1	99.999%	**99.997%**
EPOCH 2	99.543%	**99.997%**
EPOCH 3	99.998%	**99.997%**

From the chi squared table, the test interval is $22.88 < T_\chi < 56.84$. Since the computed value is within the test region, the test hypothesis H_0 cannot be rejected and the test passes.This is an indication that the presence of unmodelled systemmatic errors in the data is extremely minimal and that the modelled observations contain little or no outliers.

Table 3.4: Differentials, Percentile, Percentiles Greater Than 25%, And Dams Involved

STATIONS	Δ_{123}	percentile diff	Discrepancy	PERCENTILE	DAMS INVOLVED
from A to B	(m)	%	in cm	> 25%	IN PERCENTILE >25%
8 --- 9	-7.73443E-05	0.00	-0.01		
9 --- 5	-0.069990091	2.63	-7.00		
5 --- 9	-0.10209581	3.84	-10.21		
8 --- 5	-0.102107531	3.84	-10.21		
5 --- 2	-0.230798097	8.68	-23.08		
2 --- 8	-0.828732328	31.16	-82.87	XXXXXX	2 --- 8
8 --- 5	-0.102107531	3.84	-10.21		
5 --- 3	-0.172622119	6.49	-17.26		
3 --- 8	-0.097159023	3.65	-9.72		
8 --- 2	-0.828733	31.16	-82.87	XXXXXX	8 --- 2
2 ---3	0.392526238	14.76	39.25		
3 ---8	-0.097159023	3.65	-9.72		
8 ---3	-0.097163421	3.65	-9.72		
3 ---4	0.459306986	17.27	45.93		
4 ---8	1.831372075	68.87	183.14	XXXXXX	4 --- 8
8 --- 4	1.832261175	68.90	183.23	XXXXXX	8 --- 4
4 --- 5	2.659205921	100.00	265.92	XXXXXX	4 --- 5
5 --- 8	0.045057096	1.69	4.51		
8 --- 7	2.659205921	100.00	265.92	XXXXXX	8 --- 7
7 --- 6	0.025249948	0.95	2.52		
6 --- 8	2.233922386	84.01	223.39	XXXXXX	6 --- 8
7 --- 6	0.025236498	0.95	2.52		
6 --- 9	-0.272528121	10.25	-27.25		
9 --- 7	-0.341572957	12.84	-34.16		
9 --- 6	-0.341331784	12.84	-34.13		
6 --- 5	-0.284730525	10.71	-28.47		
5 --- 9	-0.06995203	2.63	-7.00		
6 --- 5	-0.284730525	10.71	-28.47		
5 --- 1	0.312286933	11.74	31.23		
1 ---6	-0.249090969	9.37	-24.91		
1 ---5	0.312335149	11.75	31.23		
5 --- 8	-0.10209581	3.84	-10.21		
8 ---1	-0.130956499	4.92	-13.10		
1 --- 8	-0.130937924	4.92	-13.09		
8 ---9	-7.73443E-05	0.00	-0.01		
9 ---1	-0.339370933	12.76	-33.94		
8 --- 10	-1.38065E-05	0.00	0.00		
10 --- 9	0.000232073	0.01	0.02		
9 --- 8	-7.73154E-05	0.00	-0.01		

Table 3.5: Consistency Test On Adjusted Coordinates from Least Squares

epoch 2- epoch 1	epoch 3- epoch 1		
δ12	δ13	∆123 (d.dddd)	∆123 in seconds
0.00017164413634	0.00016928021454	-0.00000236392180	-0.008510118
-0.00041914046642	-0.00041692378661	0.00000221667981	0.007980047
-0.00004359292799	-0.00005106241769	-0.00000746948970	-0.026890163
-0.00034744536926	-0.00034720646464	0.00000023890462	0.000860057
-0.00019580231873	-0.00019666347787	-0.00000086115914	-0.003100173
-0.00060521423278	-0.00060548534040	-0.00000027110762	-0.000975987
-0.00040755828964	-0.00039193388814	0.00001562440150	0.056247845
0.00023122468158	0.00025006414314	0.00001883946156	0.067822062
0.00052291817434	0.00052321424043	0.00000029606609	0.001065838
-0.00000669173714	-0.00000565060863	0.00000104112851	0.003748063
-0.00047619688268	-0.00047370913153	0.00000248775115	0.008955904
-0.00035927050390	-0.00035685993616	0.00000241056774	0.008678044
-0.00011644602308	-0.00011715437684	-0.00000070835376	-0.002550074
0.00021528476589	0.00021499480070	-0.00000028996519	-0.001043875
0.00000017419604	0.00000018693452	0.00000001273848	4.58585E-05
0.00000001683412	-0.00000007203896	-0.00000008887308	-0.000319943
-0.00000019266582	-0.00000017325211	0.00000001941371	6.98894E-05
0.00000045706158	0.00000035484750	-0.00000010221408	-0.000367971
0.00000025810096	-0.00000008850775	-0.00000034660871	-0.001247791
-0.00000023635015	0.00000026443139	0.00000050078154	0.001802814

From table 6, the column of the percentile shows differentials that have values greater than 10% (i.e. approximately 20cm). From the analysis, Dam 1, Dam 2, Dam 4 and Dam 6 were singled out. Though if 25% and above is considered, only Dam 2 and Dam 4 would be scrutinized geodetically, i.e. taking further geometric observations on the dams individually and independently.

To be able to trust the coordinates for further use, the discrepancy between δ_{12} and δ_{13} (i.e. Δ_{123}) has the standard deviation of 0.64189355 and it was subjected to a chi squared test at α=5%. The chi squared region from table is

$$8.91 < T_{\chi^2} < 32.9$$

The value obtained from the statistics $T_{\chi} = \frac{\hat{\sigma}_0^2}{\sigma_0^2}.r$ is 12.195977 with

$$r = N\text{-}1 = 20\text{-}1 = 19.$$

Since the value computed is within the statistic region, the test passes, and the coordinates are considered reliable and entitled to be included in the further deformation studies.

Table 3.6: Difference Δ123 In Seconds and In cm

	Δ in cm	PERCENTILE	PERCENTILE
		ABS VALUES	> 10%
LAT -1	-26.31517747	12.54771423	XXXXXXXX
LONG -1	24.67607965	11.76615268	XXXXXXXX
LAT -2	-83.15035934	39.64810605	XXXXXXXX
LONG -2	2.659486236	1.268107476	
LAT -3	-9.586423551	4.571039027	
LONG -3	-3.017970025	1.439041233	
LAT -4	173.9308375	82.93443764	XXXXXXXX
LONG -4	209.7208861	100	XXXXXXXX
LAT -5	3.295807712	1.571520974	
LONG -5	11.58984257	5.526317757	
LAT -6	27.6936458	13.20500133	XXXXXXXX
LONG -6	26.83444008	12.79531123	XXXXXXXX
LAT -7	-7.885394062	3.759946951	
LONG -7	-3.227892501	1.539137356	
LAT -8	0.141804765	0.067615948	
LONG -8	-0.989335122	0.471738957	
LONG -9	0.216113417	0.103048114	
LAT -9	-1.137847147	0.54255309	
LONG -10	-3.858448157	1.839801571	
LAT -10	5.574700101	2.658152082	

Table 3.7: Variances Used In Compatibility Test On Variance Ratio

EPOCH	VARIANCE
1	2.12278372568915E-09
2	2.10134107829060E-09
3	2.14714770853849E-09

The following statistical test applies:
Test Hypothesis H_0 : E $\{\hat{\sigma}_{0_1}^2\}$ = E $\{\hat{\sigma}_{0_2}^2\}$,
Alternative Hypothesis H_A: E $\{\hat{\sigma}_{0_1}^2\} \neq$ E $\{\hat{\sigma}_{0_2}^2\}$;
Test Statistic:$T_F = \frac{\hat{\sigma}_{0_1}^2}{\hat{\sigma}_{0_2}^2}$;
If the Test Statistic T_F fits the FISHER –Distribution,
$T_F \leq F_{S,f_1 f_2}$, then the test passes.
Note that S= 1 - $^{\alpha}/_{2}$; α = chosen confidence level for the test;
f_1 = network redundancy for epoch 1; f_2 = network redundancy epoch 2.

Define the test statistics as follows: T_{jk} Test statistics for difference between epoch $\boldsymbol{j}$ and $\boldsymbol{k}$

T_{12} being the test covering epoch 1 and 2 = 1.010204268

T_{13} being the test covering epoch 1 and 3 = 1.011477374

The FISHER –Distribution $F_{0.975,19\quad 19}$ = 2.532

Since T_{12} < 2.532 and T_{13} < 2.532 at a significance level of 5%, the test passes for both variances because the null Hypothesis H_0 cannot be rejected. A deformation analysis of the two epochs can be performed.

Table 3.8: Two Dimensional Network Adjustment Summary

PARAMETERS		EPOCH 1	EPOCH 2	EPOCH 3
Zigmasq	σ^2	2.122783725E-09	2.101341078E-09	2.147147708E-09
Parameters	trace(Zigmaxa)	1.43E-38	1.32193E-38	1.33E-38
Observation	trace(Zigmala1)	7.98E-42	7.31619E-42	7.43E-42
no of station		10	10	10
no of observation		78	78	78
no of parameters		20	20	20
degree of freedom		58	58	58
convergence limit		0.00001	0.00001	0.00001
quardratic form epoch 1-epoch 2				
common variance (1-2)/(1-3)/(2-3)		2.112062401e-009	2.134965717e-009	2.124244393e-009

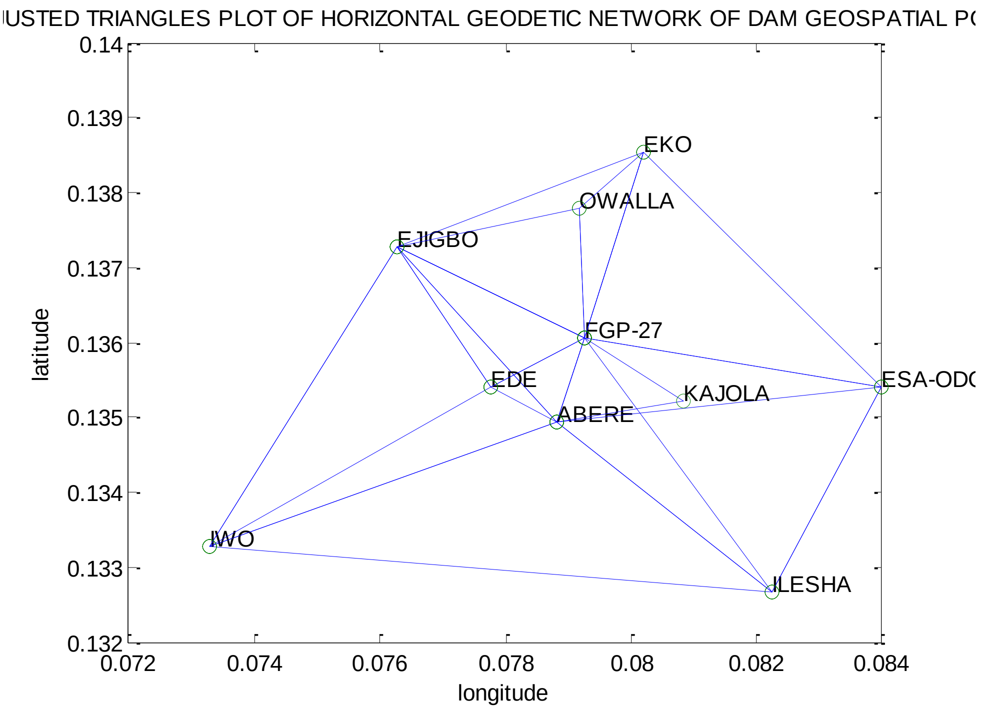

Figure 3.1: Osun Dams Network Plotting And Error Ellipse

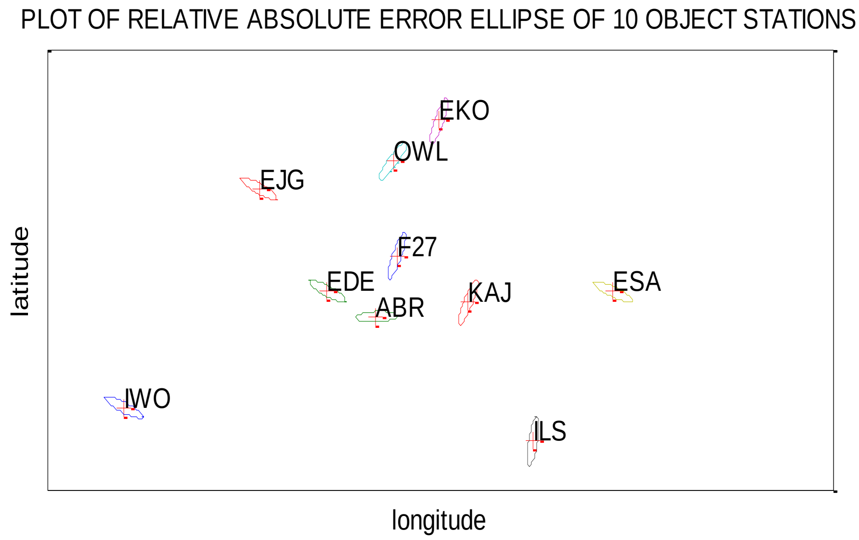

Figure 3.2: Relative Absolute Error Ellipse

Table 3.9: Local and Global Test Results

	Test Statistics TL	**Test Statistics Global TG**	**TG after S Transformation**
Epc 1 -- Epc 2	1.010204	0.426528699	0.032334
Epoch 1 -- Epoch 3	1.011477	0.40733953	0.027285

Table 3.10: Average Displacement of Dam Object Points (Against Fisher's Value)

Epoch Difference	**AVERAGE DISPLACEMENT(m)**	**F (0.05, 20,38) >>>>**	**F = 1.858**
DAM 1 - EDE	**0.967298216**	**< 1.858**	**stable**
DAM 2 - OWALLA	**0.933869438**	**< 1.858**	**stable**
DAM 3 - EKO ENDE	**1.268966977**	**< 1.858**	**stable**
DAM 4 - ESA ODO	**1.953928041**	**> 1.858**	**not stable**
DAM 5 - EJIGBO	**1.091601178**	**< 1.858**	**stable**
DAM 6 - IWO	**1.254057903**	**< 1.858**	**stable**
DAM 7 - ILESHA	**0.577310554**	**< 1.858**	**stable**

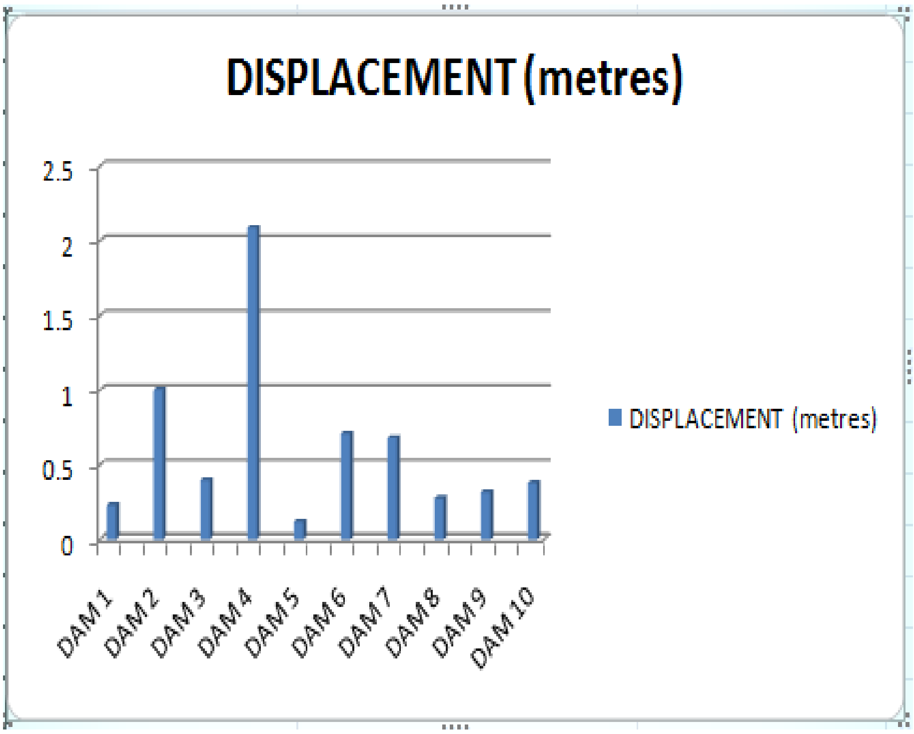

Figure 3.4: Graph Of Displacement Per Dam

4.0 Conclusion and Recommendation

The principle of least squares observation equation was employed to give statistically precise results. From the fore going, seven unknown (DAM-position) stations were computed in a single adjustment process to give adjusted results and corresponding cofactor matrices. This is an indication that the behavior of each object point could be monitored after every observation campaign covering all the dams. Once an object point is found to be statistically unfit or displaced, a more rigorous observation campaign could then be focused on such a dam, and the deformation status would be geodetically ascertained was used in epoch to epoch consideration in further studies of possible deformation on the object points.

Table 4 summarizes that a matrix 78x20 was solved in the least squares adjustment. The trace of the observation and parameters indicate strength which gives credibility to the network in the study. This was made possible because ill conditioned angles were not included in the final adjustment. Consistency of input data and the dependability of the output figures which are expected to be injected into the deformation analysis platform confirm the strength of the network. It is evident that Dam 2 and Dam 4 need to be geodetically examined further. Dams 5, 6, and 7 also need some further scientific observations. Point 8 (FGP-027) being a stable reference pillar for the work, was not considered disturbed.

Programs were written in MATLAB environment to solve the large matrices involved in the algorithm. It is hereby advised that the whole network could be re computed using Bowring formulas and compare the results with the ones published in this paper.

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