APPLICATION OF LEAST ABSOLUTE SUM (LAS) DEFORMATION DETECTION METHOD USING COORDINATE DIFFERENCES FROM DIFFERENT OBSERVATIONAL CAMPAIGNS

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Abstract: *Deformation study is one of the main research fields in geodesy. Deformation study comprises measurement, processing and analysis phases, Measurement techniques can be divided into geotechnical, structural and geodetic methods. Geotechnical and structural methods uses equipment such as tiltmeters, Pseodolites, Laser scanners e.t.c to measure changes in length, inclination, relative height, strains e.t.c. The geodetic methods are of two basic types, the reference and relative methods. This study focuses on the deformation analysis using the geodetic method known as the Least Absolute Sum Method. The method consists mainly of the independent adjustment of each of two epoch data, compatibility test on their a posteriori variances, followed by determination of Trend of movements for all the common points in the monitoring network. A triangulation network was designed (carefully selected) consisting of 45 YTT series second order control points within the study area (Lagos State) resulting in a total of 63 triangles,189 observations and 90 unknown parameters with 99 degrees of freedom. The network adjustment was done using the method of least squares observation equations. The estimated variance factors for the 2D (horizontal) network were 7.82989325645394e-08 and 7.7207636996395e-08 while 0.03944 and 0.052339 represent the estimated variance factors for the 1D (height) for the first and second epochs networks respectively. The compatibility of the two epoch data was tested with the variance ratio and compatibility test criteria. Actual displacement vectors were computed and transformed into the same computational base using S-transformation by Least Absolute Sum (LAS), stable and unstable points within the monitoring network were determined using Single Point displacement test, the displacement vector magnitude was computed for the two methods, represented graphically to indicate possible trend of movements that might have occurred. This study finds applications in studying the deformation of large engineering structures such as high rise buildings, bridges, dams, oil exploration zones, mining sites and land slide monitoring.*

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INTRODUCTION

One important application of survey control networks is the detection of expected deformations at a specified area. This is done by measurements made at successive epochs and the most probable values of the coordinates are obtained using the well-known method of least squares (James, 1985). Any object, when acted upon by external forces, deforms, or exhibits changes in its size or shape. These observable changes are manifestations of internal stresses or pressures produced by the physical interaction of the external forces and the material itself. Materials either fail or tear when stresses exceed certain critical values. (Chrzanowski et al., 1986). It is this risk of failure which practically necessitates deformation monitoring surveys, which allow the implementation of mitigating constructive procedures or evacuations to take place early enough, to prevent loss of life and material.

Generally, the deformation measurement techniques can be divided into geotechnical, structural and geodetic methods. Geotechnical and structural methods are direct measurement methods, which use special equipment to measure changes in length, inclination, relative height, strain, etc. (Teskey and Porter,1988; Chrzanowski, 1986). On the other hand, in the geodetic method there are two basic types of geodetic monitoring networks; namely the reference and relative networks (Chrzanowski et al., 1986). In a reference network, some of the points or stations are assumed to be located outside of the deformable body or object, thus serving as reference points for the determination of the absolute displacements of the object points. However, in a relative network, all surveyed points are assumed to be located on the deformable body.

This study will focus only on the geodetic method using a relative network. In a geodetic monitoring network, the object or area under investigation is usually represented by a number of points which are permanently monumented or marked. All the points are then observed in two or more epochs of time. The geodetic monitoring network can be either a conventional (terrestrial) network, a photogrammetry (i.e., aerial or close-range) network, Global Positioning System (GPS) network or a combination of these network types.

Deformation analysis using the geodetic method mainly consists of a two-step analysis via independent adjustment of the network of each epoch which involves testing coordinate differences for significance, by comparison to the accuracy of their determination, followed by deformation detection between the two epochs. During deformation analysis it is important to determine the trend of movements (displacements) for all the common points in a monitoring network. The trend of movements, then form a basis for preliminary identification of the actual deformation models. Although deformation analysis is applicable to one-dimensional (1-D), two dimensional (2-D) and three-dimensional (3-D) monitoring networks, for this study a 2D (horizontal) and 1D (vertical) networks of secondary controls located around Lagos State were investigated, a robust method, Least Absolute Sum (LAS) was used for deformation detection and analysis.

STUDY AREA

The study area is Lagos state and it is the commercial nerve centre and the most populous city in Nigeria. Lagos State is Nigeria's largest commercial, financial and industrial hub. It has industrial zones around the state with over 2000 small, medium and large scale industries. It is regarded as the smallest state in the country; however, it has the highest population density in the nation. Lagos is geographically located on latitudes and longitudes 6°35′ N 3°45′ E and 6.583°N 3.750°E Coordinates. Lagos State has a land mass of about 3,577 square kilometres with about 787 constituting lagoons, swamps, marches and creeks. Lagos harbours most of the high rise buildings, bridges and engineering structures prone to deformation or subsidence. Lagos has several networks of control points spread across different parts of the state to which surveys are tied. For this study, Secondary controls located in Lagos state were used.

DATA ACQUISITION

The study has been executed with an existing geodetic data acquired using the conventional surveying technique. An existing data of a set of control points was used to design a reference network. The data used were second order two dimensional control point coordinates obtained from the office of the Surveyor-General of Lagos State while the Orthometric heights for these selected stations in the network are derived from EGM 2008. A total of 45 common stations coordinates were used for the two epochs. Note that second epoch data in this case was simulated from the adjustment of the first epoch data for the purpose of this study. Table 3.0, below shows the coordinates of the first and second epoch data.

Table 3.0: The Coordinates of the First and Second Epoch Data

		FIRST EPOCH			SECOND EPOCH		
S/N	CONTROL POINT NAME	EASTINGS(m)	NORTHINGS(m)	HEIGHT(m)	EASTINGS(m)	NORTHINGS(m)	HEIGHT(m)
1	YTT1	512770.871400334;	718266.132200109;	22.69139892	512770.871403101;	718266.132201002;	22.6714836
2	YTT2	514506.700499577;	718531.839799538;	22.69178864	514506.700502712;	718531.839892683;	22.6177766
3	YTT3	512893.348699673;	714574.324598699;	22.32421379	512893.348696706;	714574.324682748;	22.0283972
4	YTT4	515558.463298852;	713569.142998863;	22.31915793	515558.463313656;	713569.143971483;	22.1792805
5	YTT5	516586.611797575;	714276.855800185;	22.44819168	516586.611803276;	714276.855808693;	22.4573541
6	YTT6	518643.696295812;	713094.787300631;	22.27584535	518643.696301644;	713094.787305278;	22.1277046
7	YTT7	514352.907099268;	714685.214899466;	22.40743677	514352.90709294;	714685.215000243;	22.3007829
8	YTT8	517061.729398256;	715437.606801309;	22.54378808	517061.729400602;	715437.606814866;	22.6728747
9	YTT9	518422.044396225;	714609.031901365;	22.43557176	518422.044396833;	714609.031912447;	22.4370771
10	YTT10	520125.232796594;	713647.970001077;	22.37953996	520125.232796485;	713647.97000797;	22.3638133
11	YTT11	521363.15129068;	715052.213702974;	22.48641337	521363.151281339;	715052.213730621;	22.569482
12	YTT12	518498.663596491;	716974.489604158;	22.69806547	518498.663595936;	716974.489641336;	22.9511293
13	YTT13	514108.928199661;	717481.663299636;	22.61380567	514108.928201137;	717481.663397287;	22.5929253
14	YTT14	515601.588799851;	717526.274999398;	22.70542529	515601.588808979;	717526.275961109;	22.868333
15	YTT15	516950.750999607;	716775.036400767;	22.6656666	516950.7510017;	716775.036407083;	22.851861
16	YTT16	517138.43110192;	717714.634600756;	22.76961739	517138.431104485;	717714.634610646;	23.058185
17	YTT17	520079.581892186;	717605.081806163;	22.75625371	520079.58188775;	717605.081862575;	23.0669356
18	YTT18	521384.589782752;	716820.772199095;	22.65590067	521384.589767459;	716820.772291492;	22.8672022
19	YTT19	521584.838793279;	713648.512600229;	22.32802007	521584.838781533;	713648.512604235;	22.2474788
20	YTT20	523697.284691038;	712610.341101032;	22.17827755	523697.284674975;	712610.341115527;	21.9320408
21	YTT21	525256.684295581;	712069.400902666;	22.09307778	525256.684279801;	712069.400939104;	21.7478426
22	YTT22	523497.609891544;	714124.578899686;	22.3578494	523497.609877763;	714124.578999448;	22.304579

23	YTT23	525443.708593041;	714191.748497196;	22.32616293	525443.708582496;	714191.748578731;	22.212263
24	YTT24	527124.733799406;	713617.755492013;	22.25907939	527124.733796371;	713617.755536764;	22.0740095
25	YTT25	522501.845287421;	715583.224899734;	22.49919981	522501.845274277;	715583.225000239;	22.5282929
26	YTT26	526736.830187412;	715474.552392427;	22.45949366	526736.830178688;	715474.552433881;	22.4668134
27	YTT27	527887.037415264;	714977.706471458;	22.40016023	527887.037436763;	714977.706532537;	22.3521075
28	YTT28	518840.786597038;	718875.794609559;	22.89331219	518840.786598495;	718875.794694225;	23.3294166
29	YTT29	520145.435490858;	718953.625408137;	22.9183092	520145.435486309;	718953.625481671;	23.4036233
30	YTT30	522444.869566192;	719783.514112478;	22.97815103	522444.869536483;	719783.514127727;	23.494706
31	YTT31	522025.385573317;	718114.274704924;	22.79568104	522025.385549735;	718114.274751322;	23.1433067
32	YTT32	523186.583369713;	717539.965614425;	22.71579058	523186.583341969;	717539.965648825;	22.9760665
33	YTT33	528705.879517029;	713817.503986232;	22.26302379	528705.879534535;	713817.504864103;	22.0818816
34	YTT34	528043.110511926;	712435.484798928;	22.13055794	528043.110515779;	712435.484909801;	21.8191489
35	YTT35	528419.988315911;	710633.958211361;	21.92731111	528419.98831332;	710633.958237693;	21.4137506
36	YTT36	529967.93452679;	711032.684607905;	21.95829762	529967.934544663;	711032.684711616;	21.4742604
37	YTT37	528261.861876;	717210.698619623;	22.63104409	528261.861862215;	717210.698704528;	22.8097254
38	YTT38	526425.689061496;	718724.127100844;	22.81301857	526425.689028949;	718724.127113802;	23.1712292
39	YTT39	525076.468986405;	719408.819474891;	22.91308931	525076.468977532;	719408.819551119;	23.3689151
40	YTT40	526225.935350995;	720282.574474673;	22.98975953	526225.935307325;	720282.574549655;	23.5230335
41	YTT41	528493.426463876;	718448.80777251;	22.75950388	528493.426333629;	718448.807829748;	23.0647514
42	YTT42	527884.34385114;	720371.80872944	22.9684489	527884.34360357	720371.80879708;	23.481299
43	YTT43	523273.527400817;	721154.484610349;	23.12072684	523273.527204784	721154.484704536	23.78354
44	YTT44	524356.490404865;	722381.886575353;	23.23512038	524356.488142223;	722381.886658528;	24.0128619
45	YTT45	525882.380108575;	722017.811261183;	23.17551393	525882.380020785;	722017.811315488;	23.8941837

Initial Checking of Data and Test on Variance Ratio

Before deformation analysis can be carried out, it is important to perform initial checking on the input data and test on the *a-posterior* variance factors of both epochs (Omogunloye 1988; 1990; 2006 and 2010). This is to ensure that common points, same approximate coordinates and same point's names were used in the two campaigns. The *a posteriori* variance factors of both epochs were then tested for their compatibility. The null and alternative hypotheses used are as proposed by (Setan 1995; Caspary 1987; Chen et al. 1990; Cooper 1987; Singh 1999)

$$H_o: \sigma_{o1}^2 = \sigma_{o2}^2$$

and

$$H_a: \sigma_{o1}^2 > \sigma_{o2}^2 \ or \ \sigma_{o2}^2 > \sigma_{o1}^2$$

With $\sigma_{o1}^2 \ and \ \sigma_{o2}^2$ being the a-*posteriori* variance factors for the first and second campaigns respectively.

The test statistic is $$T = \frac{\sigma_{oj}^2}{\sigma_{oi}^2} \sim F(\alpha, df_j, df_i) \qquad [3.11]$$

With *j* and *i* representing the larger and smaller variance factors, **F** is the Fisher's distribution, α is the chosen significance level (typically α = 0.05) and df_i and df_j are the degrees of freedom for i and j observation campaigns respectively. The above test is accepted if $T < F(\alpha, df_j, df_i)$ at a significance level α. The failure of the above test may be caused by incompatible weighting between the two campaign observations or incorrect weighting scheme and any further analysis is stopped at such stage.

TREND ANALYSIS

After the test on the variance ratio, the test is accepted, the displacement vector (coordinates differences) and its cofactor matrix is then computed as follows

$$\mathbf{d} = \hat{\mathbf{x}}_2 - \hat{\mathbf{x}}_1 \qquad (90 \ x \ 1 \ matrix) \qquad [3.12]$$

$$\mathbf{Q_d} = \mathbf{Q}_{\widehat{x1}} + \mathbf{Q}_{\widehat{x2}} \qquad (90 \ x \ 90 matrix) \qquad [3.13]$$

d is the displacement vector, $\mathbf{Q_d}$ is the cofactor matrix of **d**, $\hat{x}_1$ and $\hat{x}_2$ are the estimated coordinates of all the common points in the first and second observation epochs respectively (with same datum definition), $\mathbf{Q}_{\widehat{x1}}$ and $\mathbf{Q}_{\widehat{x2}}$ are the cofactor matrix of the estimated coordinates $\hat{x}_1$ and $\hat{x}_2$.

Least Absolute Sum (LAS)

Chen, (1983) has proposed a robust method known as Least Absolute Sum (LAS). This robust method was developed at the University of New Brunswick, Canada. In the LAS method, some points in a reference network cannot be accepted as stable .In other words not every point has equal importance .Hence in the beginning, the weight matrix (W) is accepted as W = I . While datum determines, this indicates that all points in the network have the same importance. Therefore, the solution is similar to the Helmert transformation, if some points are given unit weight and the others a zero weight, that is, W = diag (I,0).

The LAS methods are used when there is no previous information about the movement of points within the network.

$$\mathbf{d}^{k+1} = [\mathbf{I} - \mathbf{H}(\mathbf{H}^T\mathbf{W}^{(k)}\mathbf{H})^{-1}\mathbf{H}^T\mathbf{W}^{(k)}]\mathbf{d}^k = \mathbf{S}^{(k)}\mathbf{d}^{(k)} \quad [3.14]$$

I = identity matrix

k = number of iterations

d = displacement vector

S = S-transformations matrix

W = weight matrix

Then displacement values (d) are calculated as:

$$d_1 = S_1 d \quad [3.15]$$

$$Qd_1 = SQ_dS^T \quad [3.16]$$

$$S = I - H(H^T WH)^{-1} H^T W \quad [3.17]$$

$$d_2 = S_2 d_1 \quad [3.18]$$

$$Qd_2 = S_2 Q_d S_2^T \quad [3.19]$$

where d_1 and Q_{d1} are the displacement vector and its cofactor matrix respectively based on the new datum or computational base, ***H*** is the inner constraints matrix constructed depending on the union of the datum defects in the two epochs and on the number of common points, and ***W*** is the weight matrix with diagonal value of one for datum points and zero elsewhere. Matrix S is symmetric only for the minimum trace solutions. (i.e., all points in the network were defined as datum).The group of selected datum points is then tested for its stability by using Single Point displacement test.

Formation of Matrix H for the Final S-Transformation

H is a configuration matrix for the datum defect, called inner constraint matrix. Basically, the matrix **H** depends on the type of network: 1D, 2D or 3D. For 1D, 2D and

3D networks, **H** is having maximum dimensions of (1**m** by 1), (2**m** by 4) and (3**m** by 7) respectively, where **m** is the number of stations.

Equation (3.20) shows the components of the matrix H for a 1D network

$$H^T = (1\ 1\ 1\ 1\ 1 \ldots\ldots 1m) \qquad (1\ x\ 45\ matrix) \qquad [3.20]$$

For 2D surveying networks, the first two rows of the matrix H represent the translations in the x and y directions (*tx* and *ty*), the third row defines the rotation about the z axis for a (*rz*) and the last row is the scale of the network. Equation (3.2.4.1) shows the components of the matrix H

$$\text{2D network} \boldsymbol{H^T} = \begin{bmatrix} 1 & 0 & 1 & 0 & \cdots & 0 & 1 \\ 0 & 1 & 0 & 1 & \cdots & 1 & 0 \\ y_1^o & -x_1^o & y_2^o & -x_2^o & \cdots & -y_m^o & -x_m^o \\ x_1^o & y_1^o & x_2^o & y_2^o & \cdots & x_m^o\ c & y_m^o \end{bmatrix} \qquad (4\ x\ 90\ matrix) \qquad [3.21]$$

Where x_i^o *and* y_i^o, z_i^o are the coordinates of point p_i which are reduced to the centroid or centre of gravity of the network, i.e.,

$$x_i^o = x_i - \frac{(\sum_{i=1}^{m} x_i)}{m} \qquad (90\ x\ 1\ matrix) \qquad [3.22]$$

$$y_i^o = y_i - \frac{(\sum_{i=1}^{m} y_i)}{m} \qquad (90\ x\ 1\ matrix) \qquad [3.23]$$

With x_i, y_i, the approximate coordinates of point p_i and m is the number of common points in the network. (Kuang, 1996; Ozturk and Serbetci, 1992; Singh and Setan , 2001).The first two rows of the inner constraint matrix ($\boldsymbol{H^T}$) take care of the translations in the x and y directions, while the third row defines the rotation about the vertical (z) axis and the last row defines the scale of the network. For a trilateration network, the last row of H^T is omitted (Caspary 1987; Cooper and Cross 1991; Setan 1997; Chen et al. 1990; Singh 1999).In the first transformation ($k = 1$) the weight matrix is taken as identity ($W^{(K)} = I$) for all the common points, this indicates that all the points in the network have the same importance. The weight matrix for LAS

W^K = diag **[3.24]**

The iterative procedure continues until the absolute differences between the successive transformed displacements of all the common points i.e $\left| d^{(k+1)} - d^{(k)} \right|$ **[3.25]**

are smaller than a tolerance value δ *(say 0.001m)*. It is possible that during the iterations some *dxi, dyi, dzi may approach zero causing numerical instability because* W^K becomes very large. There are two ways to solve this problem, either

- ✓ Setting a lower bound value e.g 0.0001m . If $d_j^{(k)}$ is smaller than the lower bound value, its weight is set to zero, or replacing equation [3.26] as

$$W^K = \text{diag}\left[\frac{1}{\sqrt{(dxi^{(k)} + \delta)^2 + (dyi^{(k)} + \delta)^2)^2}}\right] \quad [3.26]$$

Where dicks is the δ component of the vector dk after kth iteration.

In this study the Least Absolute Sum minimizes the sum of the lengths of the displacements i.e

$$\sum\sqrt{(dxi)^2 + (dyi)^2} \longrightarrow \text{minimum} \quad [3.27]$$

In the final iteration, the cofactor matrix of the displacement vector is computed as

$$Q_d^{k+1} = S^{(k)} Q_d (S^{(k)})^T \qquad (90x\ 90\ matrix) \quad [3.28]$$

For 1D networks, there are some differences for the calculation of d' and Q_d'. First, the displacements d are arranged in increasing order. The median is assigned unit weight 1 and zero weight is assigned to the other displacements d. If the total number of d is an even number, the two middle (median) displacements d are assigned unit weight 1 and zero weight is assigned to the other displacements d ,Then, the new vector of displacements d' and its cofactor matrix Q_d' are

d'=$\min\sum| d_i - tz | \Rightarrow$

$Q_d' = SQ_d(S)^T$

where tz is the mean value of the middle displacements and di is the displacement of point i.

$S = I - H(H^TWH)^{-1}H^TW$ **[3.29]**

The stability information of each common point j is then determined through a single point test as below (Setan 1995; Setan and Singh 1998)

$$T_j = \frac{(d_j^{(k+1)})^T \left(Q_{dj}^{(k+1)}\right)^{-1} d_j^{(k+1)}}{2\sigma_0^2} \sim F\ (\alpha, 2, \mathrm{df}) \qquad [3.30]$$

Where;

d_j, Q_{dj} = displacement vector and its cofactor matrix respectively for each common point j or pooled variance factor.

$\sigma_o^2 = \frac{[df_1(\sigma_{01}^2)+df_2(\sigma_{02}^2)]}{df}$, common or pool variance factor [3.31]

$(\sigma_{o1}^2), (\sigma_{o2}^2)$ = *a posteriori* variance factors of first and second epochs respectively

df_1, df_2 = degrees of freedom of first and second epochs

$df = df_1 + df_2$, sum of degrees of freedom of first and second epochs

= significance level (usually chosen as 0.05)

If the above test passes (i.e., $T_j < F(\alpha, 2, df)$) then the point is assumed to be stable at a significance level α. Otherwise, if the test fails (i.e., $T_j \geq F(\alpha, 2, df)$) then the point is assumed to be deformed (moved).

RESULTS AND DATA ANALYSIS

Table 4.1a: 2D (X, Y) Network Adjustment Summary

PARAMETER	FIRST EPOCH	SECOND EPOCH
Datum Definitions	2	2
No of Station	45	45
No of Observation (n)	189	189
No of Parameters (m)	90	90
Degree of Freedom (df=n-m)	99	99
Convergence Limit	0.00001	0.00001
A-posteriori Variance (σ)	7.82989325645394e-08	7.96836000130844e-08
Trace of the Covariance Matrix of the Adjusted parameter	5.183975843652210e-06	5.27565084002794e-06
Trace of the Adjusted Observation Matrix	7.04690393080854e-06	7.17152400117759e-06

Table 4.1b: 1D (Height) Network Adjustment Summary

PARAMETER	FIRST EPOCH	SECOND EPOCH
Datum Definitions	2	2
No of Station	45	45
No of Observation (n)	107	107
No of Parameters (m)	45	45
Degree of Freedom (df=n-m)	62	62

A-posteriori Variance (σ)	0.0394472461577893	0.052339412620338
Trace of the Covariance Matrix of the Adjusted parameter	1.040613555969225	4.018695177022139
Trace of the Adjusted Observation Matrix	1.77512607710052	6.85527356791522

Deformation Analysis Result

After the network adjustment, the obtained results, especially the adjusted coordinates and the cofactor matrices were used for the computation of the displacement vector and the cofactor matrix of the displacement vector. The trend analysis and deformation detection were carried out using the LAS method. At the degrees of freedom of the epoch, the Fisher's critical value obtained at 0.05 (95%) significant level is 1.39. The result of the variance ratio test of the two epochs shows the test statistic (T) value is 1.020884677924254. The displacement vector (d), cofactor matrix of the displacement vector (Qd), the inner constraint matrix (H), weight matrix (W), S-transformation matrix (S) and other parameters of the LAS were all computed. The results of the displacement vector (d) after adjustment of the network, the first iteration displacement vector (d1) and the second iteration displacement vector (d2) after transformation by Least Absolute Sum method the final single point displacement (dp) are as shown in Table 4.2 , Table 4.3, and Table 4.4.

Table 4.2: Displacement Vector of the 1D Network and Stable and Unstable Point Displacement

		Displacement Vector	Displacement Vector on a New Computational Base After S-Transformation		Single Point Displacement	PT<Fi (0.05,2,df) PT<1.550
			$d_1 = S_1 d$	$d_1 = S_2 d_1$		
S/N	CONTROL POINT NAME	dZ(m)	dz1	dz2	PTPz	PT<1.550
1	YTT1	-0.01992	-0.62106	-0.54265	0.811994	Stable
2	YTT2	-0.07401	-0.59154	-0.51313	0.988851	Stable
3	YTT3	-0.29582	-0.45274	-0.37433	0.592596	Stable
4	YTT4	-0.13988	-0.41891	-0.3405	0.648932	Stable
5	YTT5	0.009162	-0.40332	-0.32491	0.600531	Stable
6	YTT6	-0.14814	-0.35374	-0.27533	0.409578	Stable
7	YTT7	-0.10665	-0.29257	-0.21416	0.261906	Stable
8	YTT8	0.129087	-0.28865	-0.21024	0.306232	Stable
9	YTT9	0.001505	-0.25564	-0.17723	0.191986	Stable
10	YTT10	-0.01573	-0.24738	-0.16897	0.189104	Stable
11	YTT11	0.083069	-0.2214	-0.14299	0.147021	Stable
12	YTT12	0.253064	-0.21416	-0.13575	0.13268	Stable
13	YTT13	-0.02088	-0.18804	-0.10963	0.070051	Stable
14	YTT14	0.162908	-0.18152	-0.10311	0.068049	Stable
15	YTT15	0.186194	-0.16077	-0.08236	0.044635	Stable
16	YTT16	0.288568	-0.15556	-0.07715	0.040944	Stable
17	YTT17	0.310682	-0.12838	-0.04997	0.021027	Stable
18	YTT18	0.211302	-0.12742	-0.04901	0.021141	Stable
19	YTT19	-0.08054	-0.12323	-0.04482	0.017767	Stable
20	YTT20	-0.24624	-0.106	-0.02759	0.012284	Stable
21	YTT21	-0.34524	-0.10018	-0.02177	0.013732	Stable
22	YTT22	-0.05327	-0.09834	-0.01993	0.003962	Stable
23	YTT23	-0.1139	-0.07841	0	0	Stable
24	YTT24	-0.18507	-0.02444	0.053976	0.079391	Stable
25	YTT25	0.029093	0.021583	0.099994	0.108622	Stable
26	YTT26	0.00732	0.055404	0.133815	0.308231	Stable
27	YTT27	-0.04805	0.071178	0.149588	0.449503	Stable
28	YTT28	0.436104	0.078691	0.157101	0.183723	Stable
29	YTT29	0.485314	0.103798	0.182208	0.321928	Stable
30	YTT30	0.516555	0.14556	0.223971	0.528426	Stable
31	YTT31	0.347626	0.152772	0.231183	0.514461	Stable
32	YTT32	0.260276	0.181064	0.259474	0.756523	Stable

33	YTT33	-0.18114	0.197744	0.276154	1.883885	Moved
34	YTT34	-0.31141	0.203178	0.281589	2.125777	Moved
35	YTT35	-0.51356	0.240122	0.318533	2.76796	Moved
36	YTT36	-0.48404	0.250707	0.329118	2.839587	Moved
37	YTT37	0.178681	0.328601	0.407011	2.594411	Moved
38	YTT38	0.358211	0.348322	0.426733	2.418916	Moved
39	YTT39	0.455826	0.37781	0.456221	2.445382	Moved
40	YTT40	0.533274	0.405347	0.483757	2.887476	Moved
41	YTT41	0.305247	0.409051	0.487462	3.288789	Moved
42	YTT42	0.51285	0.42577	0.504181	3.274917	Moved
43	YTT43	0.662813	0.55531	0.63372	4.707015	Moved
44	YTT44	0.777741	0.611166	0.689577	5.687355	Moved
45	YTT45	0.71867	0.670238	0.748648	6.843486	Moved

Table 4.3: The Displacement Vector Pattern of the Epoch Data using LAS

		Displacement Vector (d)		**Displacement Vector on a New Computational Base After S-Transformation By LAS**					**Single Point Displacement (PTp)**	
				Displacement Vector ($d_1 = S_1d$)		**Displacement Vector ($d_2 = S_2d_1$)**				
S/N	**CONTROL POINT NAME**	dX(m)	dY(m)	d1(X)	d1(Y)	d2(X)	d2(Y)	MAGNITUDE **$\sqrt{(d2(X)^2 + d2(Y)^2)}$**	PTp (X)	PTP(Y)
1	YTT1	2.77E-06	2.59E-05	7.20E-06	-3.17E-05	4.25E-08	-3.88E-05	3.880E-05	0.000164	0.794432
2	YTT2	3.14E-06	-0.00011	2.26E-05	5.17E-05	1.54E-05	4.46E-05	4.718E-5	0.186669	1.069351
3	YTT3	-2.97E-06	0.000105	-2.08E-05	2.24E-05	-2.79E-05	1.52E-05	3.177E-05	0.456962	0.080737
4	YTT4	1.48E-05	-0.00031	1.11E-05	0.000886	3.96E-06	0.000879	8.79E-04	0.007146	4.246152
5	YTT5	5.70E-06	0.000124	1.44E-05	-7.86E-05	7.20E-06	-8.58E-05	8.61 E-05	0.024044	4.110841
6	YTT6	5.83E-06	4.10E-05	2.28E-05	-0.0001	1.57E-05	-0.00011	1.570E-05	0.111269	7.19099
7	YTT7	-6.33E-06	0.000162	-1.23E-05	3.08E-05	-1.94E-05	2.36E-05	3.053 E-05	0.16821	0.31783
8	YTT8	2.35E-06	0.000133	2.19E-05	-6.77E-05	1.48E-05	-7.48E-05	7.625 E-05	0.103594	3.158588
9	YTT9	6.08E-07	3.72E-05	2.54E-05	-8.51E-05	1.83E-05	-9.22E-05	9.399 E-05	0.157434	4.870269
10	YTT10	-1.09E-07	2.52E-05	3.17E-05	-0.00011	2.46E-05	-0.00011	1.127 E-05	0.293329	7.62088
11	YTT11	-9.34E-06	8.80E-05	4.08E-05	-8.36E-05	3.37E-05	-9.07E-05	9.675 E-05	0.565388	4.660503
12	YTT12	-5.55E-07	8.99E-05	3.97E-05	-4.13E-05	3.26E-05	-4.84E-05	5.835 E-05	0.521227	1.323015
13	YTT13	1.48E-06	1.26E-05	1.12E-05	5.07E-05	4.09E-06	4.35E-05	5.970 E-05	0.010728	0.872408
14	YTT14	9.13E-06	-0.00053	3.06E-05	0.000906	2.35E-05	0.000899	8.993 E-05	0.300271	4.536646
15	YTT15	2.09E-06	-6.81E-05	2.92E-05	-6.40E-05	2.21E-05	-7.11E-05	7.4455 E-05	0.236805	2.868241
16	YTT16	2.56E-06	1.83E-05	3.71E-05	-5.43E-05	2.99E-05	-6.15E-05	6.838 E-05	0.452714	2.130441
17	YTT17	-4.44E-06	0.00011	5.19E-05	-2.71E-05	4.48E-05	-3.43E-05	5.642 E-05	0.986544	0.649148
18	YTT18	-1.53E-05	-4.11E-6	4.62E-05	-5.38E-06	3.90E-05	-1.25E-05	2.337 E-05	0.760024	0.086324
19	YTT19	-1.17E-05	6.57E-05	3.13E-05	-0.00012	2.42E-05	-0.00013	1.3223 E-04	0.297002	9.061258
20	YTT20	-1.61E-05	0.00012	3.67E-05	-0.00013	2.95E-05	-0.00014	1.43E-04	0.466251	1.066337
21	YTT21	-1.58E-05	0.000264	4.55E-05	-0.00012	3.84E-05	-0.00013	1.3555 E-04	0.821701	9.233006

22	YTT22	-1.38E-05	5.46E-05	4.70E-05	-3.20E-05	3.98E-05	-3.91E-05	5.607 E-05	0.809365	0.851019
23	YTT23	-1.05E-05	7.04E-05	6.56E-05	-6.19E-05	5.84E-05	-6.91E-05	9.047 E-05	1.865367	2.618017
24	YTT24	-3.03E-06	0.000137	8.24E-05	-0.00011	7.52E-05	-0.00012	1.4161 E-04	3.129756	7.668884
25	YTT25	-1.31E-05	5.91E-05	4.91E-05	-1.38E-05	4.20E-05	-2.09E-05	4.691 E-05	0.899676	0.243445
26	YTT26	-8.72E-06	2.74E-05	8.54E-05	-0.0001	7.82E-05	-0.00011	1.3496 E-04	3.326455	6.232521
27	YTT27	2.15E-05	-0.00021	0.000121	-9.17E-05	0.000114	-9.89E-05	1.509 E-04	7.224628	5.070011
28	YTT28	1.46E-06	0.000112	5.63E-05	1.86E-05	4.92E-05	1.15E-05	5.0526 E-05	1.190501	0.07579
29	YTT29	-4.55E-06	0.000126	6.08E-05	-8.46E-08	5.36E-05	-7.24E-06	5.408 E-05	1.420155	0.028761
30	YTT30	-2.97E-05	0.000272	5.85E-05	-6.64E-05	5.14E-05	-7.36E-05	8.97714 E-05	1.386828	2.965948
31	YTT31	-2.36E-05	0.000111	5.09E-05	-4.55E-05	4.38E-05	-5.26E-05	5.661 E-05	0.975635	1.507281
32	YTT32	-2.77E-05	0.000331	5.21E-05	-6.92E-05	4.49E-05	-7.63E-05	8.853 E-05	1.042566	3.237843
33	YTT33	1.75E-05	-0.00018	0.000116	0.000711	0.000109	0.000704	1.297 E-04	6.784533	2.442919
34	YTT34	3.85E-06	0.000319	8.89E-05	-6.24E-05	8.17E-05	-6.96E-05	10.732 E-05	3.947721	2.469739
35	YTT35	-2.59E-06	0.000591	7.40E-05	-0.00016	6.68E-05	-0.00017	1.833 E-04	2.844835	1.500624
36	YTT36	1.79E-05	0.000657	0.000109	-9.24E-05	0.000102	-9.96E-05	1.4256 E-04	6.39048	4.741311
37	YTT37	-1.38E-05	-0.00113	0.000103	-5.31E-05	9.58E-05	-6.02E-05	11.314 E-05	5.015102	1.936708
38	YTT38	-3.25E-05	0.000115	7.96E-05	-0.0001	7.24E-05	-0.00011	7.240 E-05	2.885911	6.487339
39	YTT39	-8.87E-06	0.001186	9.72E-05	-2.49E-05	9.00E-05	-3.20E-05	9.5519 E-05	4.402552	0.566615
40	YTT40	-4.37E-05	0.002614	7.67E-05	-2.66E-05	6.95E-05	-3.38E-05	7.728 E-05	2.663538	0.634454
41	YTT41	-0.00013	-0.00189	-3.99E-06	-7.27E-05	-1.12E-05	-7.99E-05	8.068 E-05	0.068964	3.45412
42	YTT42	-0.00025	0.00043	0.000201	-0.00036	0.000194	-0.00037	4.1778 E-05	2.121703	7.28967
43	YTT43	-0.0002	-0.00133	-9.28E-05	1.78E-05	-1.00E-04	1.06E-05	1.00498 E-04	5.378697	0.062547
44	YTT44	-0.00226	0.016168	-0.00214	9.41E-06	-0.00215	2.25E-06	2.1500 E-03	2.257432	0.002949
45	YTT45	-8.78E-05	-0.00057	4.08E-05	-3.18E-05	3.37E-05	-3.90E-05	5.154 E-05	0.621957	0.823719

Table 4.4: The Stable and Unstable Point Detection

		Displacement Vector (d2)		Stable and Unstable Point (Single Point Displacement) Using LAS			
				Single Point Displacement PT=[(dp' * inv(Qdp) * dp)/ (2*pv)]		PT<Fi (0.05,2,df) PT<1.390	
S/N	**CONTROL POINT NAME**	d2(X)	d2(Y)	PTp (X)	PTP(Y)	(X)	(Y)
1	YTT1	4.25E-08	-3.88E-05	0.000164	0.794432	Stable	Stable
2	YTT2	1.54E-05	4.46E-05	0.186669	1.069351	Stable	Stable
3	YTT3	-2.79E-5	1.52E-05	0.456962	0.080737	Stable	Stable
4	YTT4	3.96E-06	0.000879	0.007146	4.246152	Stable	Moved
5	YTT5	7.20E-06	-8.58E-05	0.024044	4.110841	Stable	Moved
6	YTT6	1.57E-05	-0.00011	0.111269	7.19099	Stable	Moved
7	YTT7	-1.94E-5	2.36E-05	0.16821	0.31783	Stable	Stable
8	YTT8	1.48E-05	-7.48E-05	0.103594	3.158588	Stable	Moved
9	YTT9	1.83E-05	-9.22E-05	0.157434	4.870269	Stable	Moved
10	YTT10	2.46E-05	-0.00011	0.293329	7.62088	Stable	Moved
11	YTT11	3.37E-05	-9.07E-05	0.565388	4.660503	Stable	Moved
12	YTT12	3.26E-05	-4.84E-05	0.521227	1.323015	Stable	Stable
13	YTT13	4.09E-06	4.35E-05	0.010728	0.872408	Stable	Stable
14	YTT14	2.35E-05	0.000899	0.300271	4.536646	Stable	Moved
15	YTT15	2.21E-05	-7.11E-05	0.236805	2.868241	Stable	Moved
16	YTT16	2.99E-05	-6.15E-05	0.452714	2.130441	Stable	Moved
17	YTT17	4.48E-05	-3.43E-05	0.986544	0.649148	Stable	Stable
18	YTT18	3.90E-05	-1.25E-05	0.760024	0.086324	Stable	Stable
19	YTT19	2.42E-05	-0.00013	0.297002	9.061258	Stable	Moved
20	YTT20	2.95E-05	-0.00014	0.466251	1.066337	Stable	Moved
21	YTT21	3.84E-05	-0.00013	0.821701	9.233006	Stable	Moved
22	YTT22	3.98E-05	-3.91E-05	0.809365	0.851019	Stable	Stable
23	YTT23	5.84E-05	-6.91E-05	1.865367	2.618017	Moved	Moved
24	YTT24	7.52E-05	-0.00012	3.129756	7.668884	Moved	Moved
25	YTT25	4.20E-05	-2.09E-05	0.899676	0.243445	Stable	Stable
26	YTT26	7.82E-05	-0.00011	3.326455	6.232521	Moved	Moved
27	YTT27	0.000114	-9.89E-05	7.224628	5.070011	Moved	Moved
28	YTT28	4.92E-05	1.15E-05	1.190501	0.07579	Stable	Stable
29	YTT29	5.36E-05	-7.24E-06	1.420155	0.028761	Moved	Stable
30	YTT30	5.14E-05	-7.36E-05	1.386828	2.965948	Stable	Moved
31	YTT31	4.38E-05	-5.26E-05	0.975635	1.507281	Stable	Moved
32	YTT32	4.49E-05	-7.63E-05	1.042566	3.237843	Stable	Moved
33	YTT33	0.00010	0.000704	6.784533	2.442919	Moved	Moved

34	YTT34	8.17E-05	-6.96E-05	3.947721	2.469739	Moved	Moved
35	YTT35	6.68E-05	-0.00017	2.844835	1.500624	Moved	Moved
36	YTT36	0.000102	-9.96E-05	6.39048	4.741311	Moved	Moved
37	YTT37	9.58E-05	-6.02E-05	5.015102	1.936708	Moved	Moved
38	YTT38	7.24E-05	-0.00011	2.885911	6.487339	Moved	Moved
39	YTT39	9.00E-05	-3.20E-05	4.402552	0.566615	Moved	Stable
40	YTT40	6.95E-05	-3.38E-05	2.663538	0.634454	Moved	Stable
41	YTT41	-1.12E-5	-7.99E-05	0.068964	3.45412	Stable	Moved
42	YTT42	0.000194	-0.00037	2.121703	7.28967	Moved	Moved
43	YTT43	-1.00E-4	1.06E-05	5.378697	0.062547	Moved	Stable
44	YTT44	-0.00215	2.25E-06	2.257432	0.002949	Moved	Stable
45	YTT45	3.37E-05	-3.90E-05	0.621957	0.823719	Stable	Stable

ANALYSIS OF RESULTS

After the presentation of results, the results were analysed as shown in the sub session below.

Trend and Deformation Analysis of the Displacements Using LAS Method

After the Least Square Estimation (LSE) of the data of the network, the compatibility of the two epochs data was tested with the variance ratio and compatibility test passed. The computed variance ratio of the campaigns is lesser than the F-distribution critical value for the specified confidence level. The critical value for the 0.05 (95%) significance level chosen for the Fisher's distribution (F) is 1.390. The test statistic (T), which is the ratio of the variances (the larger divided by the small passed. The test on the variance ratio passes at 0.05 significance level (i.e., 1.02088467792425< 1.390) of the Fisher's critical value, thus indicating the compatibility between the two epochs and permits further analysis to be carried out for deformation detection and analysis. For the 1D network, the critical value the 0.05(95%) significance level chosen for the Fisher's distribution (F) is 1.550 and it also passes the compatibility test.

The trends of movements and deformation analysis of the monitoring network was done using the adjusted coordinate differences and the cofactor matrices from both campaigns respectively and by applying the LAS method. The 1D and 2D point coordinates X, Y of each epoch and their cofactor matrices were calculated with two separate network adjustments. The Deformation program calculated displacement in X axis (dX),Y axis (dY) and (dZ).

The LAS determined the final displacement vector (dp). The data met the convergence criteria after two iterations. The displacement values obtained from the differences of the adjusted coordinates and their transformation by LAS method shows that virtually all the stations have undergone movements' overtime but this however did not result in deformation of all the point to a significant level. The single point displacement test failed for some points thus confirming the existence of deformation for some of the group of selected control points. The summary of the parameters of the deformation detection and analysis for 2D and 1D are shown in Table 4.4 and Table 4.5 respectively. The results is emphasized by the plot of single point displacement vectors ,the stable and unstable points and the relative absolute error ellipse of the 45 stations in the network as represented in Figures 4 .1, 4.2, and 4.3.

Table 4.4: Summary of some Key Parameters of the Deformation Detection and Analysis (2D)

KEY PARAMETERS	LAS
No of Iteration	2
Fisher's Distribution Critical Value for 95% Confidence Level (F)	1.390
Calculated Variance Ratio (T=rho1/rho2)	1.02088467792425
The Compatibility Test Passed (T<F)	1.02088467792425< 1.390)
Pooled Variance Factors	7.77532847804672e-08
Combined Degree of Freedom	99

Table 4.5: Summary of some Key Parameters of the Deformation Detection and Analysis (1D)

KEY PARAMETERS	SINGLE POINT DISPLACEMENT
No of Iteration	2
Fisher's Distribution Critical Value for 95% Confidence Level (F)	1.550
Calculated Variance Ratio (T=rho1/rho2)	1.327053753
The Compatibility Test Passed (T<F)	1.327053753< 1.550)
Pooled Variance Factors	0.0958933293890637
Combined Degree of Freedom	62

Figure 4.1: Displacement Vector Pattern after S-Transformation using LAS

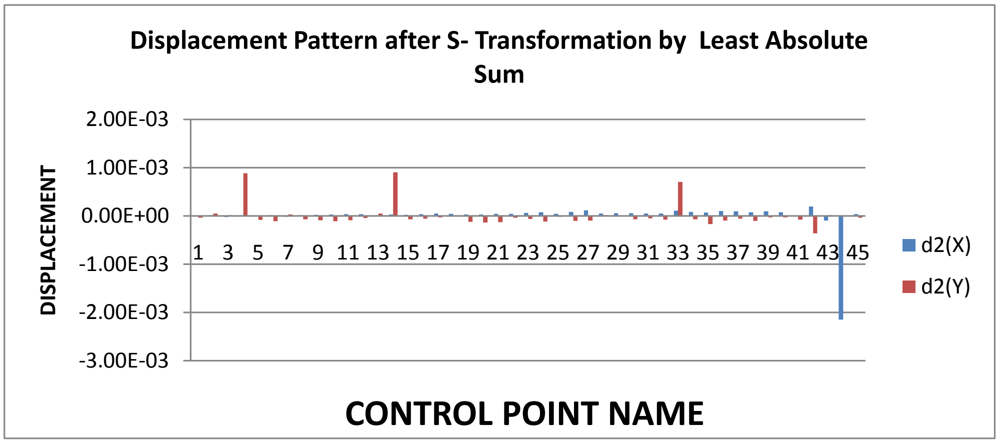
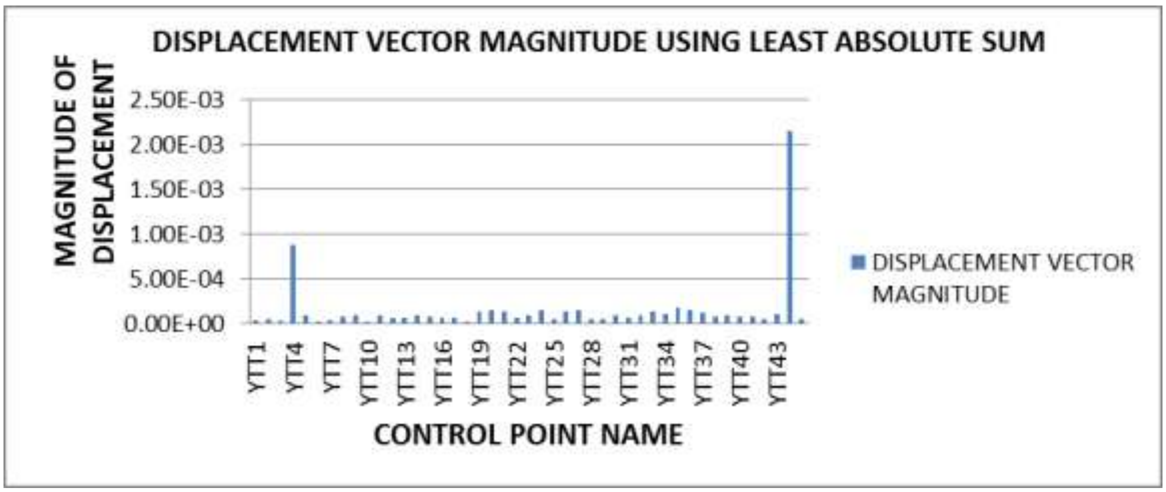


Figure 4.2: Displacement Vector Magnitude of the Stations using LAS



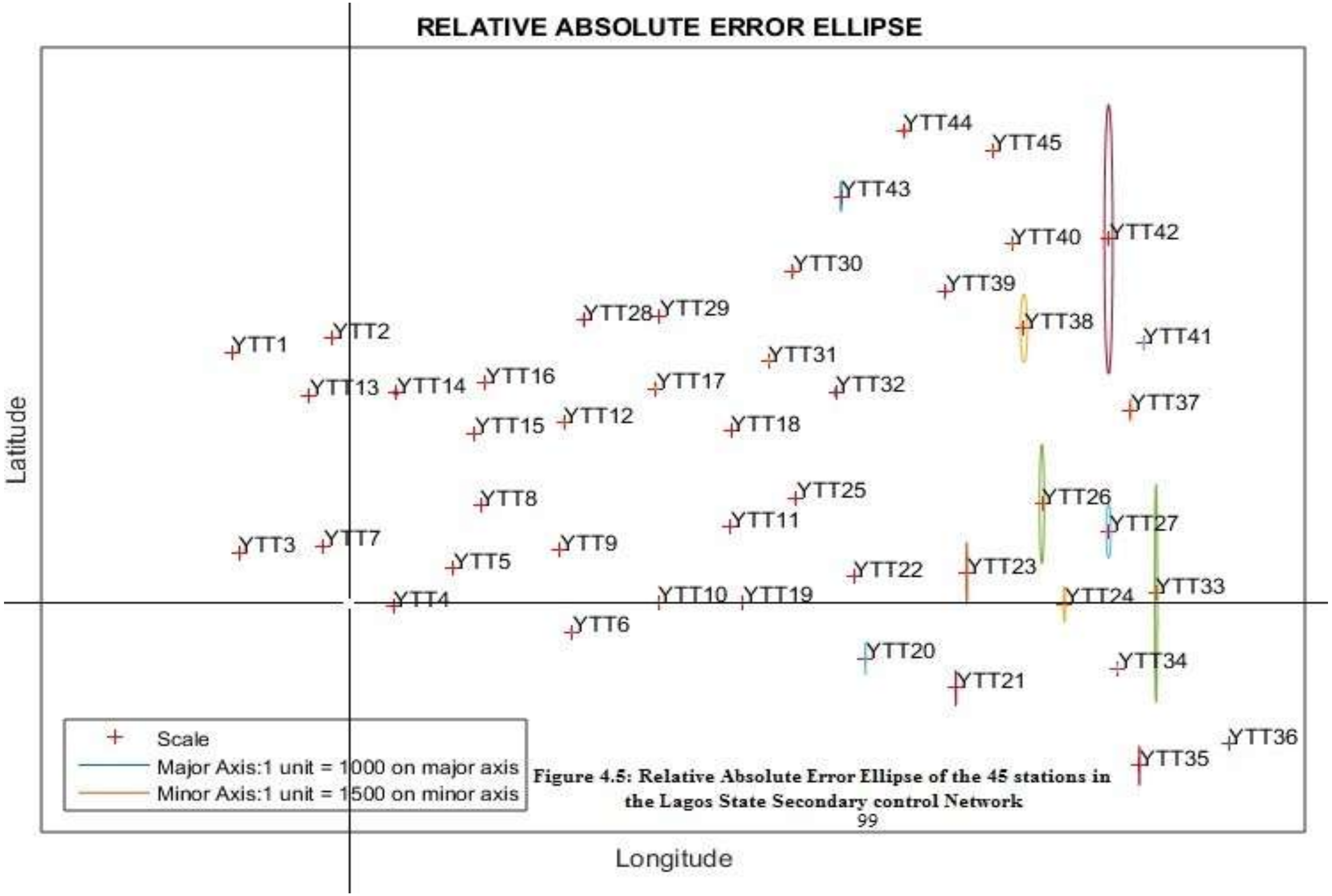


Figure 4.3: Relative Absolute Error Ellipse of the 45 Stations in the Lagos State Secondary Control Network

CONCLUSIONS

This study has presented successfully the deformation study of a geodetic monitoring network using two epochs data. The major focus has been on the identification of stable and unstable points in the network. The following conclusions are drawn from the study;

- The two epoch data were adjusted by the least square adjustment technique and passed the compatibility test and are therefore compatible.
- The displacement vector obtained from the differences of the adjusted coordinates shows that virtually all the points have undergone movements overtime but this has not however resulted in deformation within the chosen significant level of 95% confidence limit.
- The single point displacement test failed for some stations thus confirming the existence of deformation for some points. This shows that the Least Absolute Sum (LAS) has the capacity to determine stable and unstable reference points in a geodetic network. The determination of deformation status of reference points is very useful and can be applied for monitoring deformation trends in Dam Sites, Exploration areas, Tunnels and engineering structures.

RECOMMENDATIONS

Based on the work done in this study, the following points are hereby recommended:

- Using data from more than two epochs will dramatically enhance the detection of any possible change in a deformation detection and analysis study.
- As a future work, other robust and non-robust methods (e.g., Fredericton Approach, Danish Method, Total Least Square, Multi parameter Transformation, and Congruency testing methods) could be applied for the deformation detection and analysis. Furthermore dynamic model of deformation detection and prediction using the Kalman filtering methods for the velocity and acceleration determination of deformable body should be examined.
- The Survey body in this country (Nigeria), should wakeup to determine how stable her platform is, in order to avert future hazards and disaster by carrying out observations on our network of controls regularly with advanced Differential Global Positioning System (DGPS) with reference to the continuously Operating reference stations (CORS) networks.

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