APPLICATION OF ITERATIVE WEIGHTED SIMILARITY TRANSFORMATION (IWST) DEFORMATION DETECTION METHOD USING COORDINATE DIFFERENCES FROM DIFFERENT OBSERVATIONAL CAMPAIGNS

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ABSTRACT

In this study, application of deformation in geodesy is presented. Deformation analysis is one of the major research fields in geodesy and geomatics. This involves detecting and analysing change in shape and form of objects and structures on the earth surface using geodetic techniques. Deformation analysis process comprises measurement and analysis phases. Measurements can be collected using several techniques. The measurement techniques and the instruments used for such monitoring are categorized as geodetic and non-geodetic (i.e., geotechnical/structural) methods. A geodetic method was utilized in this study. This paper presents a deformation analysis of control network with a focus on procedure that consists of network design, network adjustment of individual campaigns, trend and deformation detection of the displacement field. The Iterative Weighted Similarity Transformation (IWST) robust method of analysis has been adopted and applied in determining the trend of movements and deformation detection for all the common points in the network. The developed procedure has been implemented in a program package developed using MATLAB software. Two campaign sets of data of control stations within Lagos State, Nigeria were used. The coordinate changes in the point positions were investigated. Results from the analysis indicate that all the stations have undergone movements but not all are significantly deformed. The deformation and statistical analyses shows that of the 18 stations analysed, five (5) have been significantly deformed while the remaining thirteen (13) stations are relatively stable over time.

Keywords: *Deformation, Analyses, Coordinates, Adjustment, IWST Method.*

INTRODUCTION

Deformation in the simplest form connotes change of form and shape. Since form and shape are connected to the metric characteristics of bodies, deformation, in a wider sense, is also connected with the alteration of such characteristics of general physical or even abstract entities. Deformation measurements are of great importance in the research field of surveying and geomatics engineering. The object of geodesy is the study of the size, shape, gravity field of the earth, position determination, time variation, and their graphical representations. Consequently, deformation methods find manifold applications in geodetic work and study. Geodesy involves repeated measurements to determine precise positions and rate of change in positions of stations at deformations. 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). In both geodesy and geophysical science, the forces acting to cause earth deformation are of interest, however, the geodesists primary concern is with the development of techniques and methods for the determination of such deformation. In the geodetic method, there are two basic types of geodetic monitoring networks; namely the reference (absolute) 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 paper considers the geodetic method for the deformation analysis of the network of reference stations in other to know their deformation status over the years. While there are different deformation detection and analysis methods i.e., robust and non-robust methods, the robust iterative weighted similarity transformation (IWST) method proposed by Chen (1983) has been adopted in this particular study. Robust methods are used when there is no previous information about the movement of points within the network (Chen, 1983; Singh and Setan, 1999, 1999/1, 2001). This suit the condition of the network of stations in this case as most of them have since been established with little or no information about their deformation status over the years.

A study to establish the deformation state of most of the survey reference stations in the country is very important because they form the network of controls to which surveys are tied for various construction and engineering purposes.

METHODOLOGY

Deformation analysis using the geodetic method mainly consists of a two-step analysis via independent adjustment of the network of each observation campaign followed by deformation detection between the campaigns. During deformation analysis, it is important to determine the trend of movements (displacements) for all the common points in the monitoring network. Although deformation analysis can be applied on one-dimensional (1-D), two dimensional (2-D) and three-dimensional (3-D) monitoring networks, this paper focuses on a 2-D network.

Data Acquisition

An existing geodetic data acquired using the conventional surveying technique was utilized. The data used were second order two-dimensional control station coordinates obtained from the office of the Surveyor-General of Lagos State, Nigeria. A total of 18 common stations coordinates were used for the two campaigns.

Data Processing

In all parts of the study, the data were processed using the Microsoft Office Packages, ArcGIS, and MATLAB software. A customised program package called Dapsen Adjust Deform (DAD) was developed using MATLAB software for all computational works in this study. The program package consists of two modules known as Adjustment Program and Deformation Analyses Program. The adjustment program is based on least square (LS) adjustment technique. The deformation analyses program is based on the Iterative weighted similarity transformation (IWST) robust method.

NETWORK DESIGN (STATIONS SELECTION) AND ADJUSTMENT OF EACH CAMPAIGN

A very important step in deformation measurement is the design of the network. If the network design system was poor, satisfactory results could not be obtained. The station coordinates were carefully selected, plotted and the network designed done with the AutoCAD and ArcGIS software. Adjustment of observations for each campaign was done separately to obtain the adjusted estimate of horizontal position of stations (coordinates) and their full cofactor and covariance matrices for each of the campaign. The method of least squares estimation (LSE) has been used for the adjustment and evaluation of the data sets. The LSE is an important tool in estimating the unknown parameters from the redundant data sets. The best linear unbiased estimates (BLUE) were obtained by LSE technique applied. The functional model relating the measurements and parameters to be estimated (Omogunloye 1988; 1990; 2006 and 2010) can be expressed as:

$\boldsymbol{L} = \boldsymbol{f}(\boldsymbol{X})$ [2.1]

Where $\boldsymbol{L}$ is the vector of observations and $\boldsymbol{X}$ is the vector of parameters to be estimated
In general, equation (2.1) is non-linear, and it needs to be linearized by using Taylor's theorem. Specifically equation (2.1) is written as

$\boldsymbol{L^a} = \boldsymbol{f}(\boldsymbol{X^a})$ [2.2]

After linearization the observation equation is written as

$\boldsymbol{L} \;= \boldsymbol{AX} + \boldsymbol{\widehat{V}}$ [2.3]

Where,

$\boldsymbol{L^a} = \boldsymbol{L^b} + \boldsymbol{V}$, Vector of adjusted observation [2.4]

$\boldsymbol{X^a} = \boldsymbol{X^o} + \boldsymbol{X}$, Adjusted parameter [2.5]

$\boldsymbol{L^o} = \boldsymbol{F}(\boldsymbol{X^o})$ [2.6]

$\boldsymbol{L} = \boldsymbol{L^o} - \boldsymbol{L^b}$, the misclosure vector [2.7]

$\boldsymbol{L^o}$ = Approximate vector of observation

$\boldsymbol{sL^b}$ = Original vector of observation

$\boldsymbol{X^a}$ = Vector of adjusted parameter

$\boldsymbol{X}$ = the vector of corrections to the approximate values$(\boldsymbol{X^o})$

$\boldsymbol{\widehat{V}}$ = the vector of residuals,

$\boldsymbol{A} = \frac{\mathrm{d}\boldsymbol{F}(\boldsymbol{X^o})}{\mathrm{d}(\boldsymbol{X^a})}$, the design matrix, [2.8]

$\boldsymbol{P} \;= \boldsymbol{QL^{-1}}$, a-prior weight matrix [2.9]

$\boldsymbol{QX^a} \;= (\boldsymbol{\widehat{A}}\ ^{\boldsymbol{T}} \boldsymbol{P\widehat{A}})^{-\boldsymbol{1}}$, cofactor matrix of $\boldsymbol{X_a}$ [2.10]

$\boldsymbol{QL^a} = \boldsymbol{A}(\boldsymbol{\widehat{A}}\ ^{\boldsymbol{T}} \boldsymbol{P\widehat{A}})^{-\boldsymbol{1}}\boldsymbol{\widehat{A}}\ ^{\boldsymbol{T}}$, cofactor matrix of adjusted observations [2.11]

$\boldsymbol{Q_V} = \boldsymbol{P^{-1}} - \boldsymbol{A}(\boldsymbol{\widehat{A}}\ ^{\boldsymbol{T}} \boldsymbol{P\widehat{A}})^{-\boldsymbol{1}}\boldsymbol{\widehat{A}}\ ^{\boldsymbol{T}}$, cofactor matrix of the residuals [2.12]

$\boldsymbol{\sigma_o^2} = \frac{\boldsymbol{\widehat{V}}\ ^{\boldsymbol{T}} \boldsymbol{P\widehat{V}}}{\boldsymbol{n-m}}$, a posteriori variance factor [2.13]

n = number of observations,

m = number of parameters,

For the general system comprised of n observations and m unknown parameters:
The normal equation for least squares solutions is:

$$(\hat{A}^{T} P\hat{A})X = \hat{A}^{T} PL \qquad [2.14]$$

This equation can be rearranged to yield the least squares estimate of the unknown parameters, in this case the coordinates of the points in the network. This gives the best estimate of their values:

$$X = (\hat{A}^{T} P\hat{A})(\hat{A}^{T} PL) \qquad [2.15]$$

Although the estimated parameters, X^{a} (i.e., coordinates of the points) and the cofactor matrix QX^{a}, are datum dependent based on the choice of zero-variance computational base, there exist functions such as $\hat{V}$, Q_{V} , L^{a}, σ_{o}^{2} and QL^{a}, which are datum invariant.

The normal equation with a full rank and the *a priori* variance factor (σ_{o}^{2}) is assumed to be known (i.e., $\sigma_{o}^{2} = 1$).

After first step of LSE, iteration was done. Limit for iteration is (Setan, 2008):
1. $\widehat{X_{\iota}}$ close to zero
2. $\widehat{V_{\iota}} - V_{t-i}$ close to zero
3. $\hat{V}^{T} P\hat{V}$ Stable
In this study, the third limit in terms of the stability of $\hat{V}^{T} P\hat{V}$ was used.

INITIAL CHECKING OF DATA AND COMPATIBILITY TEST ON VARIANCE RATIO

Before deformation analysis can be carried out it is important to perform initial checking on the input data and compatibility test on the a-posterior variance factors of both campaigns.
For this study, the initial checking of data was done. This was to ensure that common stations, same approximate coordinates and same station's names were used in the two campaigns. Common stations in both campaigns were extracted and the deformation analysis carried out on them. The a-posteriori variance factors of both campaigns 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).

$H_o: \sigma_{o1}^2 = \sigma_{o2}^2$ [2.20]

and

$H_a: \sigma_{o1}^2 > \sigma_{o2}^2 \ or \ \sigma_{o2}^2 > \sigma_{o1}^2$ [2.21]

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

$$T = \frac{\sigma_{oj}^2}{\sigma_{oi}^2} \sim \mathrm{F}(\alpha, \mathrm{d}f_j, \mathrm{d}f_i) \quad [2.22]$$

With j and i representing the larger and smaller variance factors, $\mathbf{F}$ is the Fisher's distribution, α is the chosen significance level (α = 0.05 has been used in this study) and $\mathrm{d}f_i$ and $\mathrm{d}f_j$ are the degrees of freedom for i and j observation campaigns respectively.

The above test is accepted if $T < F(\alpha, df_j, \mathrm{d}f_i)$ 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

The IWST method is based on S-transformation (Similarity or Helmert transformation) as represented in equation (2.25) below (Chen, 1983; Chen et al. 1990; Setan and Singh 1998b, c; Singh and Setan 1999a, b, c; Singh 1999; Setan and Singh 1999). The IWST method is used after the displacement vector (coordinates differences) and its cofactor matrix has been computed according to equations (2.23) and (2.24).

After the test on the variance ratio (equation 2.22) is accepted, the displacement vector (coordinates differences) and its cofactor matrix is then computed as follows

$d = \hat{x}_2 - \hat{x}_1$ [2.23]

$Q_d = Q_{\widehat{x1}} + Q_{\widehat{x2}}$ [2.24]

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

The IWST method is as follows:

$$d^{k+1} = [I - G(G^T W^{(k)} G)^{-1} G^T W^{(k)}] d^k = S^{(k)} d^{(k)} \quad [2.25]$$

Where

I = identity matrix

k = number of iterations

d = displacement vector (equation 3.25)

S = S-transformation matrix

W = weight matrix

$$G^T = \begin{bmatrix} 1 & 0 & 1 & 0 & \cdots & 0 & 1 \\ 0 & 1 & 0 & 1 & \cdots & 1 & 0 \\ y_1^o & -x_1^o & y_2^o & -x_2^o & \cdots & -y_m^o & -x_m^o \\ x_1^o & y_1^o & x_2^o & y_2^o & \cdots & x_m^o & y_m^o \end{bmatrix} \quad [2.26]$$

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

$$x_i^o = x_i - \frac{(\sum_{i=1}^m x_i)}{m} \quad [2.27]$$

$$y_i^o = y_i - \frac{(\sum_{i=1}^m y_i)}{m} \quad [2.28]$$

With x_i, y_i the approximate coordinates of point p_i and m is the number of common points in the network.

The first two rows of the inner constraint matrix (G^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 G^T is omitted (Caspary 1987; Cooper and Cross 1991; Setan 1997; Chen et al. 1990; Singh 1999).

Transformation Of Both Campaigns Into The Same Datum

The S-transformation is applied to transform matrix d and Q_d into a common datum definition (either minimum trace solutions) (Caspary 1987; Cooper 1987; Fraser and Gruendig 1985; Biacs and Teskey 1990). The same has been done in this study with total minimum trace solution as follows:

$$d_1 = Sd \quad [2.29]$$

$$Q_{d1} = SQ_d S^T \quad [2.30]$$

$$S = I - G(G^T W^{(k)} G)^{-1} G^T W^{(k)} \quad [2.31]$$

where $\boldsymbol{d_1}$ and $\boldsymbol{Q_{d1}}$ are the displacement vector and its cofactor matrix respectively based on the new datum or computational base, $\boldsymbol{G}$ 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 $\boldsymbol{W}$ is the weight matrix with diagonal value of one for datum points and zero elsewhere. Matrix $\boldsymbol{S}$ is symmetric only for the minimum trace solutions (i.e., all points in the network were defined as datum).

In the first transformation ($\boldsymbol{k} = \boldsymbol{1}$) the weight matrix is taken as identity ($\boldsymbol{W^{(K)}} = \boldsymbol{I}$) for all the common points, this indicates that all the points in the network have the same importance.
Then in the ($\boldsymbol{k} + \boldsymbol{1}$) transformation the weight matrix is defined as

$$\boldsymbol{W^{(k)}} = \text{diag}\left\{\frac{\boldsymbol{1}}{\left|\boldsymbol{d_i^{(k)}}\right|}\right\} \qquad [2.32]$$

It is important to mention that the above weighting schemes (equations 2.32) are only applied on the common datum points (i.e., either the reference points for a reference network or a group of points in a stable block for a relative network), whilst for the object points the weight is set as zero (i.e. $\boldsymbol{W^{(k)}} = \boldsymbol{0}$). The iterative procedure continues until the absolute differences between the successive transformed displacements of all the common points (i.e., $|\boldsymbol{d_i^{(k+1)}} - \boldsymbol{d_i^{(k)}}|$) are smaller than a tolerance value $\boldsymbol{\delta}$ (say 0.01m). It is possible that during the iterations some $\boldsymbol{d_i^{(k)}}$ or (dx_i, dy_i) may approach zero, causing numerical instabilities, because $\boldsymbol{W^{(k)}}$ (equations 2.32) becomes very large. The problem is addressed in two ways. The problem is addressed either by
(i) Setting a lower bound value (e.g., 0.00000001 [m]). If $\boldsymbol{d_i^{(k)}}$ is smaller than the lower bound value, its weight is set to zero, or
(ii) Replacing equations 2.32

$$\boldsymbol{W^{(k)}} = \text{diag}\left\{\frac{\boldsymbol{1}}{[\left|\boldsymbol{d_i^{(k)}}\right| + \boldsymbol{\delta}]}\right\} \qquad [2.33]$$

This technique was found to be useful in avoiding numerical instabilities. The second approach has been adopted in this study to prevent any of such numerical instabilities.
The IWST method minimizes the total sum of absolute values of the displacement components (i.e., $\sum |d_i| \Rightarrow$minimum). In the final iteration the cofactor matrix of the displacement vector is computed as

$$\boldsymbol{Q_d}^{\boldsymbol{k+1}} = \boldsymbol{S^{(k)}} \boldsymbol{Q_d} (\boldsymbol{S^{(k)}})^{\boldsymbol{T}} \qquad [2.34]$$

Single Point Displacement Test

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

$$T_j = \frac{(d_j^{(k+1)})^T (Q_{dj}^{(k+1)})-1(d_j^{(k+1)})}{2\sigma_o^2} \sim F(\alpha, 2, \mathrm{df}) \quad [2.35]$$

Where;

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

$$\sigma_o^2 = \frac{[df_1(\sigma_{o1}^2)+df_2(\sigma_{o2}^2)]}{df}, \text{ common or pool variance factor} \quad [2.36]$$

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

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

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

α = significance level (the chosen level is 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., $T_j \geq F(\alpha, 2, \mathrm{df})$) then the point is assumed to be deformed (moved).

RESULTS AND DISCUSSION

Results

The results of the study are as presented in the sections below.

Network Design and Adjustment Results

After the network design, the data was further processed and the network adjusted. The network points are as shown in Figure 3.0 below.

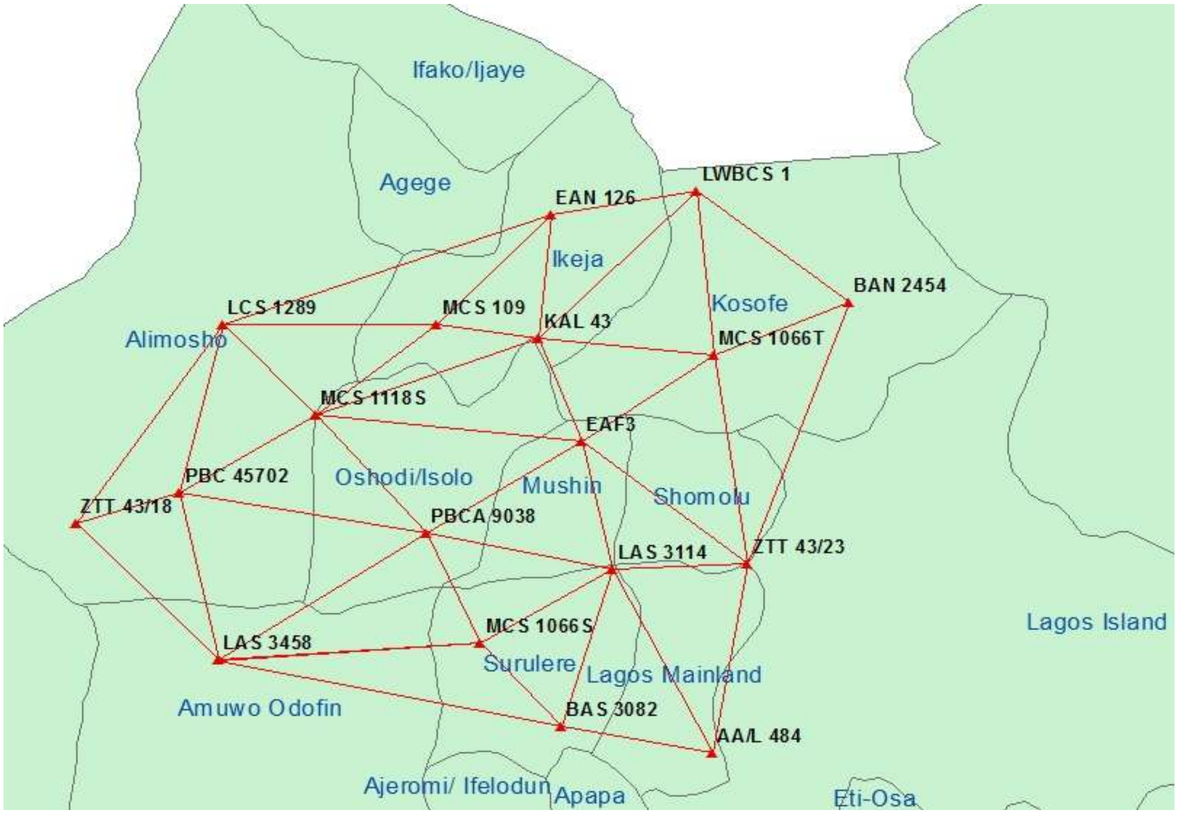

Figure 3.0: The Network Points Overlaid on a Section of Map of the Study Area

The first and second campaigns data met the convergence criteria. The result of the adjusted coordinates of the campaign data is as shown in Table 3.0

Table 3.0: The Campaign Differences (Adjusted Coordinates)

The Campaign Differences (Adjusted Coordinates)							
	Adjusted First Campaign		**Adjusted Second Campaign**		**Control Point Name**	**Coordinate Differences**	
Stn No	**Eastings (m)** E_1	**Northings (m)** N_1	**Eastings (m)** E_2	**Northings (m)** N_2		**Eastings (m)** $E_2 - E_1$	**Northings (m)** $N_2 - N_1$
1	542372.9110	716579.5224	542372.9347	716579.5190	**AA/L 484**	0.0237	-0.0034
2	539445.9621	722201.7541	539445.9399	722201.8464	**LAS 3114**	-0.0222	0.0923
3	543414.9296	722342.2230	543414.8636	722342.2566	**ZTT 43/23**	-0.066	0.0336
4	537942.7534	717372.8565	537942.7588	717372.8748	**BAS 3082**	0.0054	0.0183
5	542396.3929	728751.5752	542396.4605	728751.5838	**MCS 1066S**	0.0676	0.0086
6	527879.6938	719406.0707	527879.6378	719406.0974	**LAS 3458**	-0.056	0.0267
7	533992.9164	723296.7524	533992.9214	723296.7570	**PBCA 9038**	0.005	0.0046
8	526770.4919	724529.6437	526770.3397	724529.5459	**PBC 45702**	-0.1522	-0.0978
9	523720.6157	723581.9171	523720.6373	723581.9792	**ZTT 43/18**	0.0216	0.0621
10	528013.8361	729686.9774	528013.827	729686.0227	**LCS 1289**	-0.0091	-0.9547
11	530765.5523	726905.3509	530765.554	726905.3444	**MCS 1118S**	0.0017	-0.0065
12	534300.2717	729689.8767	534300.2700	729689.8999	**MCS 109**	-0.0017	0.0232
13	537628.7846	733032.9740	537628.7811	733033.0096	**EAN 126**	-0.0035	0.0356
14	537285.8904	729276.1914	537284.8687	729276.2420	**KAL 43**	-1.0217	0.0506
15	541920.0595	733783.8888	541920.0942	733783.9877	**LWBCS 1**	0.0347	0.0989
16	546353.0675	730372.1615	546353.0628	730372.1215	**BAN 2454**	-0.0047	-0.04
17	535568.1457	719956.0912	535568.2058	719956.1157	**MCS 1066T**	0.0601	0.0245
18	538546.1209	726106.7730	538546.1042	726106.7783	**EAF3**	-0.0167	0.0053

The summary of some key parameters of the network adjustment are as shown in Table 3.1.

Table 3.1: Summary of Some Key Parameters of the Network Adjustment

PARAMETER	FIRST CAMPAIGN	SECOND CAMPAIGN
Datum Definitions	2	2
No of Station	18	18
No of Observation (n)	75	75
No of Parameters (m)	36	36
Degree of Freedom (df=n-m)	39	39
No of Iteration	10	10
A-Posteriori Variance (σ)	1.850e-19	1.696e-19
Trace of the Covariance Matrix of the Adjusted Parameter	0.5300	0.5044
Trace of the Adjusted Observation Matrix	2.000e-08	1.903e-08

Deformation Analysis Result

The trend analysis and deformation detection were carried out using the IWST method. The results are shown this section. At the degrees of freedom of the campaigns, the Fisher's critical value obtained at 0.05 (95%) significant level is 1.7045. The result of the variance ratio test of the two campaigns shows the test statistic (T) is 1.0907. The displacement vector (d), cofactor matrix of the displacement vector (Qd), the inner constraint matrix (G), weight matrix (W), S-transformation matrix (S) and other parameters of the IWST were all computed. The results of the stable and unstable points are as shown in Table 3.2.

Table 3.2: The Stable and Unstable Point Detection

STABLE AND UNSTABLE POINT (SINGLE POINT DISPLACEMENT) USING IWST							
Stn. No	**Final Iterated Displacements (dp)**		**Single Point Displacement PT=[(dp' * inv(Qdp) * dp) / (2*pv)]**		**Single Point Displacement Magnitude (dm) from PT dm = $\sqrt{dY^2 + dX^2}$**	**PT<Fi (0.05,2,df)**	**Control Point Name**
	dY for dp (m)	**dX for dp (m)**	**dY for PT (m)**	**dX for PT (m)**		**PT<1.70447**	
1	-0.0121	0.02006	-0.00852	0.0048	0.0098	**Stable**	AA/L 484
2	0.07469	-0.02194	0.44391	-0.07798	0.4507	**Stable**	LAS 3114
3	0.01618	-0.07183	-0.01107	0.25324	0.2535	**Stable**	ZTT 43/23
4	0.00801	0.00854	0.00322	-0.01175	0.0122	**Stable**	BAS 3082
5	-0.01885	0.06269	-0.06304	2.73717	2.7379	**Unstable**	MCS 1066S
6	0.01231	-0.03755	0.00739	0.11256	0.1128	**Stable**	LAS 3458
7	-0.01526	0.01369	-2.53213	-0.05934	2.5328	**Unstable**	PBCA 9038
8	-0.12023	-0.13245	0.33222	3.23707	3.2541	**Unstable**	PBC 45702
9	0.04077	0.04614	0.06505	0.22186	0.2312	**Stable**	ZTT 43/18
10	0.01501	0.00822	0.01323	-0.0073	0.0151	**Stable**	LCS 1289
11	-0.03224	0.01498	0.48498	-0.04022	0.4866	**Stable**	MCS 1118S
12	-0.00654	0.00575	0.0037	-0.05316	0.0533	**Stable**	MCS 109
13	0.00105	-0.0014	-0.00024	-0.00062	0.0007	**Stable**	EAN 126
14	0.02179	-0.0187	0.01334	0.01507	0.0201	**Stable**	KAL 43
15	0.06365	0.03012	0.42584	-0.2096	0.4746	**Stable**	LWBCS 1
16	-0.06953	-0.01588	-0.43978	1.88173	1.9324	**Unstable**	BAN 2454
17	0.00993	0.06663	0.00879	0.49206	0.4921	**Stable**	MCS 1066T
18	-0.01849	-0.01537	-2.11571	-0.01043	2.1157	**Unstable**	EAF3

DISCUSSIONS

Least Square Estimation of the Network

In the first step of the process, the data from each of the campaigns were processed separately. Both campaigns met the convergence criteria. The estimated variance factors were 1.850e-19 and 1.696e-19 for the first and second campaigns respectively showing a difference of 1.539e-

20. The result shows the variance factor of the first campaign is larger than the second by the ratio 1.0907. The combined variance factor is 1.773e-19 (average of the two campaigns). The trace of the covariance matrices of adjusted parameter and observation for the first and second campaigns are 0.5300 and 0.5044 for the parameters and 2.000e-08 and 1.903e-08 for the observations. Average redundancy number is 0.52 for both campaigns, thus indicating that the network possesses a high degree of reliability.

Trend and Deformation Analysis of the Displacements Using IWST Method

After the least square estimation (LSE) of the data, the compatibility of the two campaigns data was tested. The critical value for the 0.05 (95%) significance level chosen for the Fisher's distribution (F) is 1.7045. The first campaign with 1.850e-19 has the larger variance and second campaign has 1.6961e-19. The variance ratio of the two campaigns is 1.0907. The test on the variance ratio passes at 0.05 significance level (i.e., $1.0907 < 1.7045$), thus indicating the compatibility between the two campaigns and permits further analysis to be carried out for deformation detection and analysis.

The displacement values obtained from the differences of the adjusted coordinates and their transformation by IWST method shows that virtually all the stations have undergone movements' overtime but this however did not result in deformation of all the station to the chosen significant level. The single point displacement test failed for some stations thus confirming the existence of deformation for some of the group of selected control stations. The deformation results showed that the total of 13 stations passed the test, that is, stations 1,2,3,4,6,9,10,11,12,13,14,15 and 17 were confirmed as stable and the rest of the stations as significantly deformed. The result shows stations 5, 7, 8 16 and 18 have been subjected to deformation and unstable. The maximum and minimum single point displacement vector recorded is at stations 8 and 13 with the values of 3.237m and -0.24mm. Station 8 has the highest displacement vector magnitude of 3.254m and 0.66mm is the lowest on station 13. The significant difference for the single point displacement vector can be found in station 8 with critical value 2.905m. For the stable stations, the displacements recorded are not necessarily due to deformation but could be as a result of other factors e.g survey errors. Table 3.3 shows the summary of some key parameters of the deformation analysis. This result is emphasized by the plot of the stable and unstable stations and the relative absolute deformation error ellipse of the 18 stations in the horizontal network as represented in Figures 3.1 and 3.2.

Table 3.3: Summary of Some key parameters of the Deformation Analysis

KEY PARAMETERS	SINGLE POINT DISPLACEMENT
Fisher's Distribution Critical Value for 95% Confidence Level (F)	1.7045
Calculated Variance Ratio (T=rho1/rho2)	1.0907
The Compatibility Test Passed (T<F)	(i.e., 1.0907 < 1.7045)
Pooled Variance Factors	1.773e-19
Combined Degree of Freedom (df=df1+df2)	78
No of Iteration	2
Stable Points Detected	13 (Stations 1,2,3,4,9,10,11,12,13,14,15,17)
Unstable Points Detected	5 (Stations 5,7,8,16,18)

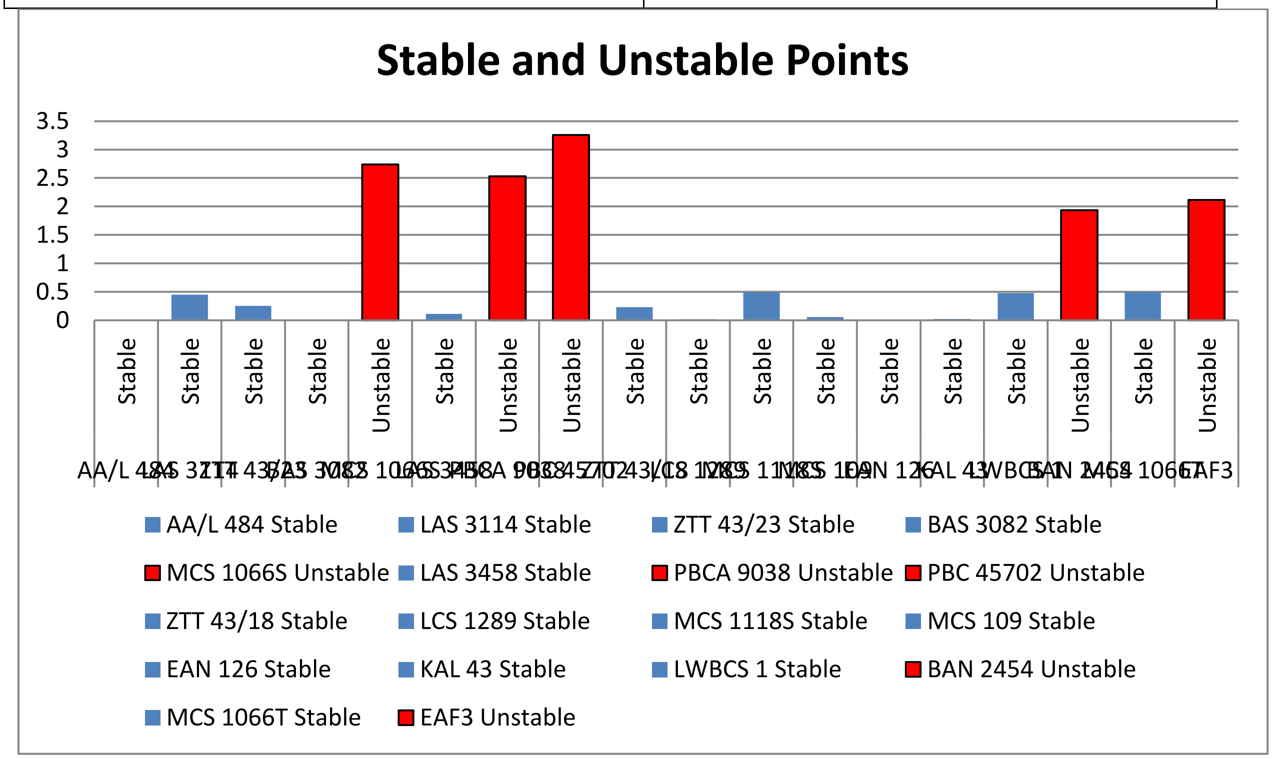

Figure 3.1: Stable and Unstable Stations

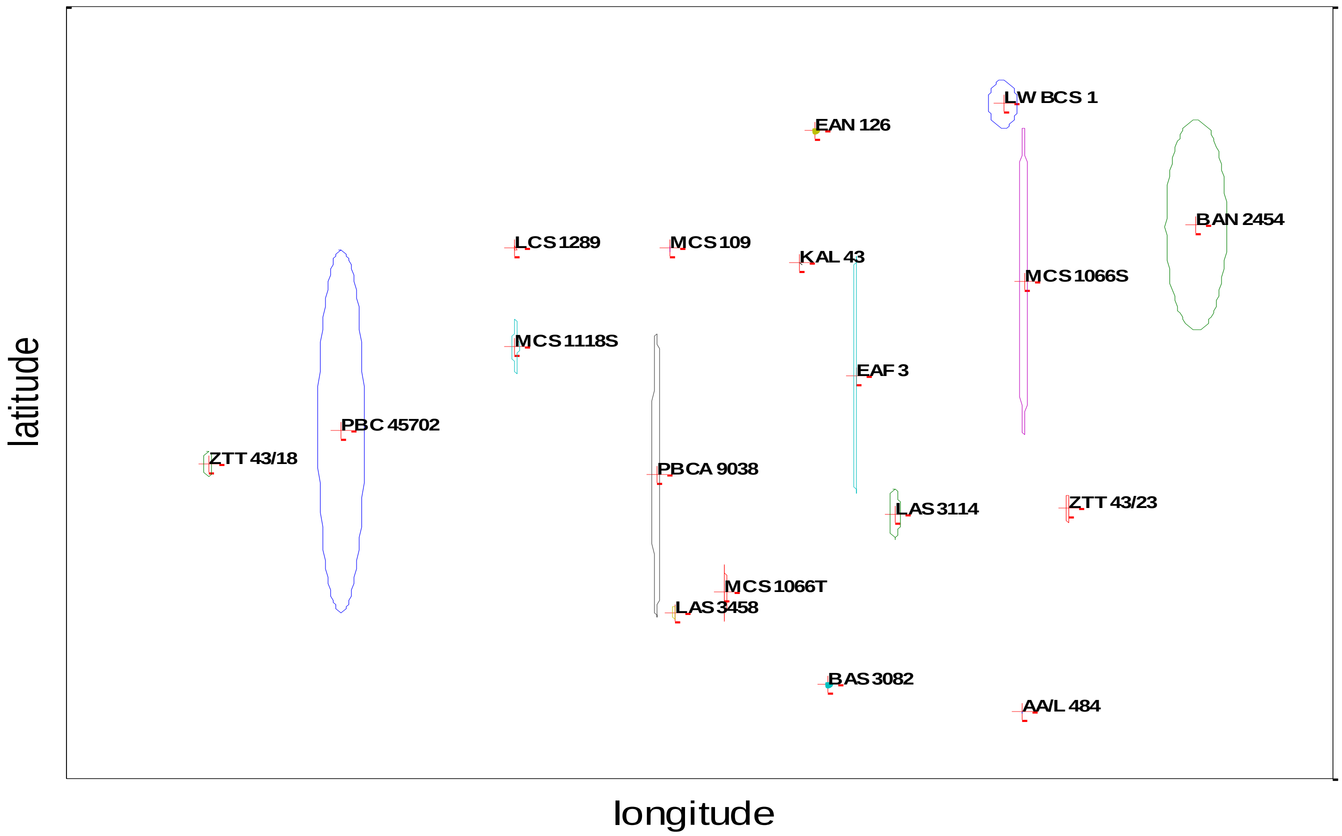

Figure 3.2: Relative Absolute Error Ellipse of the 18 Stations in Lagos State Horizontal Network with the Station Name

CONCLUSIONS

This study has presented successfully the application of deformation analysis in geodesy using coordinate difference between the results of compatible adjustment based on data from two different observational campaigns.

The following conclusions are hereby drawn from the study:

- The two campaigns data are well adjusted by the Least Squares Adjustment Technique (LSA) 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 however has not resulted in deformation of all the point within the chosen significant level of 95% confidence limit.

- The coordinate differences obtained from the Least Squares Estimation (LSE) indicate that the displacements vectors at some of the selected stations are to the magnitude of 0.003 to 0.099m.
- The single point displacement test failed for some stations thus confirming the existence of deformation for some of the stations in the control network examined. The deformation results showed that the total of 13 stations passed the single point displacement test, that is, stations 1,2,3,4,6,9,10,11,12,13,14,15 and 17 were confirmed as stable and the rest of the stations as significantly deformed. The result shows stations 5, 7, 8 16 and 18 have been subjected to deformation.

This shows that the Iterative Weighted Similarity Transformation (IWST) method has the capability of determination of stable and unstable reference points in reference networks. This could help in selection of the best minimum constraints and the best deformation models at the later stages of the deformation analysis. The application of deformation in geodesy is very useful and can be applied for economic planning of alignment surveys of the machine and monitoring deformation trends in sites like Dam, Tunnel, engineering structures as well as large control network.

RECOMMENDATIONS

From the foregoing, the following recommendations are made:

- There is need to carry this kind of study for all the control stations in the country to ascertain there deformation status. The 3-D deformation study is urgently necessary.
- There is also the need to study the stability of areas where exploitation of minerals, dams, bore-holes and high rise buildings are located in the country so as to provide cautions and safety against future hazards and disaster.

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