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Distortion of Oil and Gas Infrastructure from Geomatics Support View

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Abstract

Above surface vertical circular tanks are commonly used in industries for storing crude oil, petroleum products, etc. and for storing water in public water distribution systems. Such tanks require periodic surveys to monitor long-term movements and settlements of the foundation or short-term deflections and deformation of the structures. One of the most effective geometric parameters of circular vertical tanks is determining it's out of roundness, distortion and the deformation as a result of age. To ensure the security of civil engineering structures, it is necessary to carry out periodic monitoring of the structures. To develop a reliable and cost effective monitoring system for the storage oil tanks, the deformation monitoring scheme consisted of measurements made to the monitored tank from several monitoring stations (occupied stations), which were established around the tanks. The circular cross section of the oil storage tanks were divided into several monitoring points distributed to cover the perimeter of the cross section. These monitoring points (studs) were situated at equal distances on the outer surface of the tanks and located around the tank base .

Geodetic instruments were setup at these monitoring stations (occupied stations) and observations carried out to determine the coordinates of monitoring points on the tank surface.

Keywords: monitoring, deformation, diameter, oil volume, intersection, accuracy, oil tanks.

INTRODUCTION

The Forcados Yokri field is located in OMLs 43 and 45 in Burutu Local Government Area of Delta State of Nigeria. It is bounded approximately by the co-ordinates 319453mE to 335236mE and 148355mN to 141626mN with area coverage of 244.64sq. Km (24464.0 hectares). The entire Forcados Yorkri area features meandering creeks and mangrove swamp. The land terrain is covered by mangrove forest. The area has a humid tropical climate characterized by high rainfall and high temperature (Ehigiator, 2005). The Tanks at Forcados Terminal were constructed in the 70ths, therefore their structural integrity have been of major concern to both local community and environmentalists. Although API 653 remain the industry standard relative to tank inspection and maintenance, the frequency of testing and inspection can also be affected by various state and local regulations(Ehigiator, 2005).

Figure 1: Forcados and Environs

During the last decade, the world of engineering surveying has seen enormous developments in the techniques for spatial data acquisition. One of these developments has been the appearance of geodetic Total station

The tanks which were designed with floating roof plate of thickness 6.0mm were constructed in the 70s with the following properties (Ehigiator, 2005).

1. Norminal Diameter: 76.2m
2. Temperature: 58ºf
3. Nominal Volume 100,000m³
4. Height 22m
5. Liquid Gravity 0.85 to 0.9
6. API 650 @ atmospheric temperature
7. The hydrostatic pressure is 2 bars

Thickness: we have ten segments at vary thickness

1. Bottom plate Thickness 6.0mm
2. 1^{st} plate thickness 34.5mm
3. 2^{nd} plate thickness 30.6mm
4. 3^{rd} plate thickness 26.7mm
5. 4^{th} plate thickness 22.9mm
6. 5^{th} plate thickness 19.0mm
7. 6^{th} plate thickness 15.0mm
8. 7^{th} plate thickness 11.3mm
9. 8^{th} plate thickness 10.0mm
10. 9^{th} plate thickness 10.0mm

Monitoring Of Vertical Storage Tanks

It is necessary to model the structure of oil storage tank by using well-chosen discrete monitoring points located on the surface of the structure at different levels which, when situated correctly, accurately depict the characteristics of the structure.

Any movements of the monitoring point locations (and thus deformations of the structure) can be detected by maintaining the same point locations over time and by performing measurements to them at specified time intervals. This enables direct point displacement comparisons to be made. A common approach for this method is to place physical targets on each chosen discrete point to which measurements can be made. However, there are certain situations in which monitoring the deformations of a large structure using direct displacement measurements of targeted points is uneconomical, unsafe, inefficient, or simply impossible. The reasons for this limitation vary, but it may be as simple as placement of permanent target prisms on the structure is too difficult or costly (Ashraf, 2010). To obtain the correct object point displacements (and thus its deformation), the stability of the reference stations and control points must be ensured. The main conclusion from the many papers written on this topic states that every measurement made to a monitored object must be connected to stable control points (Ashraf, 2010). This is accomplished by creating a reference network of control points surrounding a particular structure (figure 2). To develop a reliable and cost effective monitoring system of any of the storage oil tanks, deformation monitoring scheme consisted of measurements made to the tanks from several monitoring stations (occupied stations), which are chosen in the area around the tank, that are referred to several reference control points (Gain, 2008). The geodetic instruments are setup at these monitoring stations (occupied stations) and observations carried out to determine the coordinates of monitoring points on the tank surface.

The circular cross section of the oil storage tank is divided into several monitoring points distributed to cover the perimeter of this cross section, as shown in figure 1. These monitoring points are situated at equal distances on the outer surface of the tank. The (stud) points are fixed, with each stud carrying an identification number and made permanent throughout the life of the tank. The purpose is to maintain the same monitoring point during each epoch of observation.

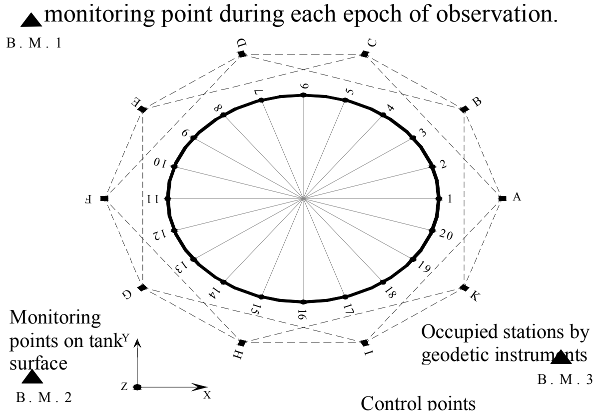


Figure 2 – Structural deformation monitoring system

To determine the coordinates of occupied stations around the monitored oil storage tank, traverse network was run from the control points around the vicinity of the tank to connect the bench marks used for the monitoring.

The easiest way of visualizing the traversing process around the tank is to consider it as the formation of a polygon on the ground using standard survey procedures. The traverse was being measured using total station. The slope distances and horizontal angles were measured to survey stations on both faces for a given number of rounds, and recorded accordingly. Appropriate corrections were applied, and the distances reduced to horizontal distance. In this work, traverse network around tank № 9 is presented (as shown in figure 3).

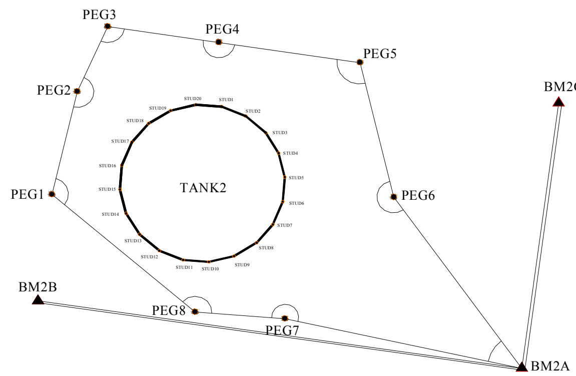


Figure 3. Traverse network for determining the coordinates of occupied stations

In fig. 3, three control points (BM2A, BM2B and BM2C) with known coordinates were fixed around the tank. Eight occupied stations (PEG1, PEG2, …, PEG8) were established. To determine the coordinates of the eight occupied stations, a closed loop traverse was designed around tank № 9 as shown in figure 3.

In this closed traverse there are 9 interior angles and 9 side lengths. The observed interior angles and sides of the traverse loop together with computed accuracy using Calson2011 software are presented in table 1.

Computation and Adjustment of Observations

By using least square theory, method of condition equation the traverse loop traverse was adjusted as follows:

The number of total observations (n) = 10 angles + 10 distances = 20.

The number of conditions (r) = 3 and these include:

1. Angular misclosure condition:

Δ_1 = (Σ interior angle of loop traverse) - (n_{angles} -2)(180°) (1)

2. Sum of the departures is equal to zero (2)

$$\Delta_2 = \sum_{i=1}^{n} D_i * Sin\ \theta_i$$

Where D_i – the length of traverse side, θ_i – bearing of traverse side

3. Sum of the latitude is equal to zero:

$$\Delta_3 = \sum_{i=1}^{n} D_i * \cos \theta_i \qquad (3)$$

Hence, the number of necessary observations:

$n_o = n - r = 17 \qquad (4)$

The first step in solving traverse using conditional least square is finding the adjusted values of observations (9 interior angles and 9 lengths) and its accuracy. Secondly, from these values and accuracies, the adjusted coordinates of the traverse stations (eight occupied points) and its accuracy can be determining depending on the geometry of the traverse figure. All of these steps were carried out using Carlson2011 program. The adjusted coordinates of the traverse stations are presented in table 1.

Table 1 – Least – square solution of Tank 9 observations

Process Least-Squares Results

Raw file: C:/Users/Ehigiator Raphael/AppData/Roaming/Carlson Software/Carlson2011/ICAD/SUP/TANK9.rw5

Coordinate file:

Least-Squares Closure

Control Points

Point#	Easting	Northing
1	324871.298	148355.212
2	324646.398	148390.115
11	324646.398	148390.115

Distance Observations

Occupy	FSight	Distance	StdErr
2	3	238.670	0.035
3	4	152.605	0.035
4	5	144.176	0.035
5	6	224.836	0.035
6	7	132.289	0.035
7	8	142.874	0.035
8	9	305.188	0.035
9	10	142.232	0.035
10	11	130.610	0.035

Angle Observations

BSight	Occupy	FSight	Angle	StdErr
1	2	3	2°18'04"	25.227"
2	3	4	267°21'20"	39.678"
3	4	5	184°04'45"	55.715"
4	5	6	266°14'38"	42.142"
5	6	7	270°21'28"	44.368"
6	7	8	5°30'41"	42.679"
7	8	9	353°52'06"	33.839"
8	9	10	187°06'19"	43.971"
9	10	11	356°08'41"	43.044"

Adjusted Point Comparison

	Original		Adjusted			
Point#	Easting	Northing	Easting	Northing	Dist	Bearing
3	324880.585	148344.073	324880.584	148344.073	0.001	N 79°33'35" W
4	324858.086	148193.136	324858.084	148193.137	0.002	N 60°22'25" W
5	324826.739	148052.409	324826.737	148052.410	0.003	N 52°43'53" W
6	324604.551	148086.810	324604.548	148086.812	0.003	N 66°05'34" W
7	324625.608	148217.413	324625.603	148217.415	0.005	N 64°34'19" W
8	324589.424	148079.197	324589.422	148079.199	0.003	N 43°37'48" W
9	324634.738	148381.002	324634.728	148381.006	0.010	N 68°13'07" W
10	324673.092	148517.965	324673.079	148517.970	0.014	N 67°51'08" W

Adjusted Points

Point#	Easting	Northing	N-StdErr	E-StdErr
3	324880.584	148344.073	0.002	0.002
4	324858.084	148193.137	0.003	0.003
5	324826.737	148052.410	0.003	0.006
6	324604.548	148086.812	0.005	0.006
7	324625.603	148217.415	0.004	0.004
8	324589.422	148079.199	0.004	0.006
9	324634.728	148381.006	0.003	0.002
10	324673.079	148517.970	0.002	0.004

Solution Converged in 2 Iterations

Reference Standard Deviation: 0.072

Chi-Square statistic: 0.107, Range for 95%: 0.103 to 5.990

Adjustment Passed Chi-Square test at 95% confidence level

Max adjustment: 0.014

Starting Point 2: E 324646.398 N 148390.115 Z 0.000

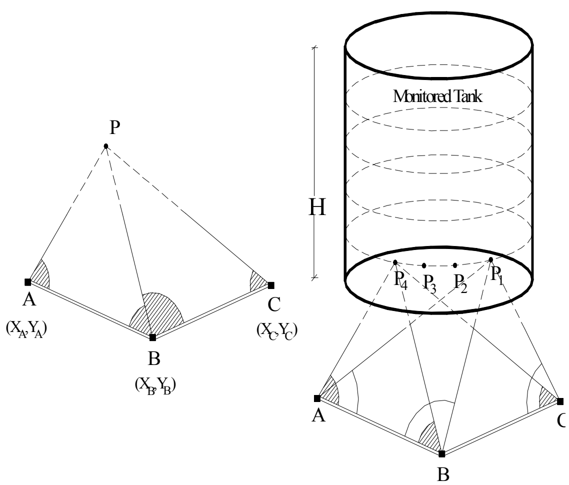
Backsight Point 1: E 324871.298 N 148355.212 Z 0.000

Point No.	Horizontal Angle	Zenith Angle	horz Dist	Inst HT	Rod HT	Easting	Northing	Elev	Description
3	AR2.1804	90.0000	238.669	0.000	0.000	324880.584	148344.073	-0.000	PEG1A
4	AR267.2121	90.0000	152.604	0.000	0.000	324858.084	148193.137	-0.000	PEG2A
5	AR184.0445	90.0000	144.175	0.000	0.000	324826.737	148052.410	-0.000	BM-9B
6	AR266.1437	90.0000	224.837	0.000	0.000	324604.548	148086.812	-0.000	BM-9A
7	AR270.2126	90.0000	132.290	0.000	0.000	324625.603	148217.415	-0.000	BM-9C
8	AR5.3040	90.0000	142.873	0.000	0.000	324589.422	148079.199	-0.000	PEG3A
9	AR353.5205	90.0000	305.189	0.000	0.000	324634.728	148381.006	-0.000	PEG4A
10	AR187.0619	90.0000	142.232	0.000	0.000	324673.079	148517.970	-0.000	BM-5C
11	AR356.0842	90.0000	130.609	0.000	0.000	324646.398	148390.115	-0.000	X

By the same way, the coordinates of occupied stations around each oil storage tank of ten studied tanks in the studied area in Forcados Terminal Nigeria were determined. It is important to note that the number of monitoring points on the tank surface and the number of occupied stations around each tank differ from one tank to another depending on the topography and visibility around (Ehigiator, 2005).

Determining the coordinates of tank surface points using linear-angular 2D intersection

To achieve accurate determination of coordinates of monitoring points on the outer surface of oil tank at Forcados terminal and its accuracy during the process of structural deformation monitoring, linear-angular intersection was used. This is because it has the advantages of least squares application. In this case, four observations were carried out from the two occupied stations (two distances and two angles). In angular intersection or linear intersection, the number of observations (two angles or two distances) equals the number of unknowns (coordinates of point P) but in case of linear-angular intersection the number of observations is more than the number of unknowns, and consequently least square method must be used to determine the coordinates of point P (figure 4). Figure (4) illustrates the geometry of the linear-angular intersection. There are two known coordinates points (X_A, Y_A) and (X_B, Y_B). From these two known points (A and B), we can determine the coordinates of unknown point P; (X_P, Y_P) by measuring horizontal angles α_1 and α_2 and horizontal distances S_1 and S_2. Adjustment will be carried out in this case by using observation equation method.



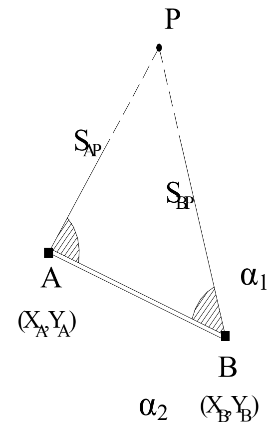


Figure 4 – Geometry of linear - angular intersection for determining point coordinates

It is important to note that the horizontal distances S_1, S_2 was measured by using reflectorless total station. Modern total station has reflectorless ability, so it can measure the inclined distance and horizontal distance without prisms.

In this model of adjustment (observational least square), the number of equations equals the number of observations (n = 4), every equation contains one observation and one or more than one unknowns. In this case, the observations are (S_1, S_2, α_1, α_2) and the unknowns are (X_P, Y_P).

The two lengths of the lines (S_1, S_2) in horizontal projection can be written in coordinates form as:

$$S_1 = \sqrt{(X_P - X_A)^2 + (Y_P - Y_A)^2}$$
$$S_2 = \sqrt{(X_P - X_B)^2 + (Y_P - Y_B)^2} \quad (5)$$

From figure (2), the horizontal angles (α_1 and α_2) can be calculated as follows:

$$\left.\begin{aligned} \alpha_1 &= \cos^{-1}\left(\frac{AP^2 + AB^2 - PB^2}{2.AP.AB}\right) \\ \alpha_2 &= \cos^{-1}\left(\frac{BA^2 + BP^2 - AP^2}{2.BA.BP}\right) \end{aligned}\right\} \tag{6}$$

By using the coordinates of points, we can write equation (2) as:

$$\left.\begin{aligned} \alpha_1 &= \cos^{-1}\left[\frac{(X_P - X_A)^2 + (Y_P - Y_A)^2 + AB^2 - (X_P - X_B)^2 - (Y_P - Y_B)^2}{2\ AB\ \sqrt{(X_P - X_A)^2 + (Y_P - Y_A)^2}}\right] \\ \alpha_2 &= \cos^{-1}\left[\frac{(X_P - X_B)^2 + (Y_P - Y_B)^2 + AB^2 - (X_P - X_A)^2 - (Y_P - Y_A)^2}{2\ AB\ \sqrt{(X_P - X_B)^2 + (Y_P - Y_B)^2}}\right] \end{aligned}\right\} \tag{7}$$

The equations 5 and 7 are the four observational equations, these equations are nonlinear function of both parameters and observations; they can be treated by least squares adjustment technique. The first step in the solution is finding the approximate values of unknowns. The approximated values (input data) of coordinates of point **P** (Vector X^0) can be assumed by using angular intersection according to the following formulae (Ehigiator, 2005):

$$\left.\begin{aligned} X_P^0 &= \frac{X_A \cot \alpha_2 + X_B \cot \alpha_1 - Y_A + Y_B}{Cot\ \alpha_1 + Cot\ \alpha_2}, \\ Y_P^0 &= \frac{Y_A \cot \alpha_2 + Y_B \cot \alpha_1 - X_A + X_B}{Cot\ \alpha_1 + Cot\ \alpha_2}. \end{aligned}\right\} \tag{8}$$

By substituting these approximate values in the four observation equations, the approximate values of observations (L^0) can be computed, and then we can compute the misclosure vector (L) as follows:

$$L = L^0 - L_{obs}\ . \tag{9}$$

The linearised model may be expressed in the matrix form as follows:

$$\underset{(4,1)}{V} = \underset{(4,2)}{A} . \underset{(2,1)}{X} + \underset{(4,1)}{L} \tag{10}$$

Where A – the coefficient matrix of parameters with dimension (4, 2); L – The misclosure vector with dimension (4, 1); V – The residuals vector.

Matrix A can be computed by differentiation of the four equations with respect to the two unknowns and can be written in the form:

$$A_{(4,2)} = \begin{bmatrix} \frac{\partial S_1}{\partial X_P} & \frac{\partial S_1}{\partial Y_P} \\ \frac{\partial S_2}{\partial X_P} & \frac{\partial S_2}{\partial Y_P} \\ \frac{\partial \alpha_1}{\partial X_P} & \frac{\partial \alpha_1}{\partial Y_P} \\ \frac{\partial \alpha_2}{\partial X_P} & \frac{\partial \alpha_2}{\partial Y_P} \end{bmatrix} \tag{11}$$

By using MathCAD program, the elements (a_{ij}) of the matrix (**A**) can be found by differentiating the four observation equations.

Then, the normal equation system is written thus:

$$\underset{(2,2)}{N} . \underset{(2,1)}{\hat{X}} + \underset{(2,1)}{U} = 0 \tag{12}$$

Where,

$$\underset{(2,2)}{N} = \underset{(2,4)}{A^T} \cdot \underset{(4,4)}{W} \cdot \underset{(4,2)}{A} \quad (13)$$

And

$$\underset{(2,1)}{U} = \underset{(2,4)}{A^T} \cdot \underset{(4,4)}{W} \cdot \underset{(4,1)}{L} \quad (14)$$

The solution for normal equation is

$$\underset{(2,1)}{\hat{X}} = -\underset{(2,2)}{N^{-1}} \cdot \underset{(2,1)}{U} \quad (15)$$

Then, the adjusted unknown parameters can be estimated as:

$$\underset{(2,1)}{\bar{X}} = \underset{(2,1)}{\hat{X}} + \underset{(2,1)}{X^0} \quad (16)$$

The vector of adjusted observations can be estimated as:

$$\underset{(4,1)}{\bar{L}} = \underset{(4,1)}{L} + \underset{(4,1)}{\hat{V}} \quad (17)$$

The estimated variance factor is:

$$\sigma_0^2 = \frac{V^T.W.V}{r} = \frac{V^T.W.V}{2} \quad (18)$$

The estimated variance covariance matrix of parameters is:

$$C_X = \sigma_0^2 . N^{-1} \quad (19)$$

Finally, the variance covariance matrix of the adjusted observations can be computed as:

$$C_L = A \; .C_X \, .A^T \quad (20)$$

By using **MathCAD** program, the above normal equation can be solved.

The error in point position M_P can then be determined by using the following formula (Allen, 1988):

$$M_P = \frac{b \; m_\alpha^{//}}{\rho^{//} \sin \gamma_1} \sqrt{\sin^2_{\alpha_1} + \sin^2_{\beta_1}}, \quad (21)$$

Where b – base line (the distance between occupied stations) (for example b=AB in fig. 2); $m^{//}_\alpha$ – mean square error of measuring horizontal angles (taken from specifications of applied instrument); $\rho^{//} = 206265^{//}$, γ_1 - the horizontal angle at p.

In order to accept the observations and adjusted coordinates of point P from the two triangles ABP and BCP, it is necessary that the coordinates must satisfy the following condition (Ashraf, 2010).

$$r_P = \sqrt{\Delta_X^2 + \Delta_Y^2} \leq 3 M_t, \quad (22)$$

Where $\Delta_X = X_1^P - X_2^P$; $\Delta_Y = Y_1^P - Y_2^P$ and $M_t = \sqrt{M_1^2 + M_2^2}$.

X_1^P, Y_1^P - Coordinates of point P from first triangle (ABP); X_2^P, Y_2^P - Coordinates from second triangle (BCP); M_1, M_2 – Error in point position for the first and second triangles respectively (Ashraf 2010).

If the coordinates satisfy condition (22), the corrected coordinates of point P can be determined by the arithmetic mean of two triangles.

$$X_P = \frac{X_1^P + X_2^P}{2}, \qquad Y_P = \frac{Y_1^P + Y_2^P}{2} \quad (23)$$

The accuracy of coordinates of monitoring point P can then be determined using least square method, consider the following procedure

Determining the radius of the tank and its associated distortion

From coordinates of several points (more than three points) on the circumference of circular section, the radius of the tank r and coordinates of center (X_C, Y_C) can be determined using least square method as following:
For any monitoring point on circular section of tank surface (X_i, Y_i) must be fulfilled the equation of circle (Allan, 1988):

$$\left(\hat{x}_i - \hat{x}_c\right)^2 + \left(\hat{y}_i - \hat{y}_c\right)^2 - \hat{r}^2 = 0 \qquad i= 1, 2, 3, \ldots, n \tag{24}$$

Where: X_C, Y_C – the coordinates of center of circular section, r – the corrected value of radius.

The general form of least square as following:

$$\underset{(n,u)}{A} \cdot \underset{(u,1)}{X} + \underset{(n,m)}{B} \cdot \underset{(m,1)}{V} + \underset{(n,1)}{L} = \underset{(n,1)}{0} \tag{25}$$

Where:
n – The number of equations (in this case equals the number of monitoring points because each equation has one monitoring point);

u – The number of unknowns (in this case equals 3; radius r and coordinates of center X_C, Y_C);

m – The number of observations (in this case m = 2 n; because each point has two coordinates X, Y).

By applying least square theory, approximates values of unknowns (radius r^0 and coordinates of center X^0, Y^0) must be assumed or calculated. To achieve this goal

The coordinates of center can be approximated by the arithmetic mean of coordinates. As following

$$X_C^0 = \frac{\sum_{i=1}^{n} X_i}{n}, \tag{26}$$

Approximate value of radius r^0 can be obtained from tank manual or by using three points on the perimeter of tank to estimate it.

The matrices can be formed by the following methods:

$$\underset{(n,1)}{L} = \begin{bmatrix} (X_1 - X_C^0)^2 + (Y_1 - Y_C^0)^2 - (r^0)^2 \\ (X_1 - X_C^0)^2 + (Y_1 - Y_C^0)^2 - (r^0)^2 \\ \ldots \\ \ldots. \\ (X_1 - X_C^0)^2 + (Y_1 - Y_C^0)^2 - (r^0)^2 \end{bmatrix} \tag{27b}$$

$$\underset{(n,3)}{A} = \begin{bmatrix} \frac{\partial f_1}{\partial X_C} & \frac{\partial f_1}{\partial Y_C} & \frac{\partial f_1}{\partial r} \\ \frac{\partial f_2}{\partial X_C} & \frac{\partial f_2}{\partial Y_C} & \frac{\partial f_2}{\partial r} \\ \ldots & & \\ \frac{\partial f_n}{\partial X_C} & \frac{\partial f_n}{\partial Y_C} & \frac{\partial f_n}{\partial r} \end{bmatrix} = \begin{bmatrix} -2(X_1 - X_C^0) & -2(Y_1 - Y_C^0) & -2r \\ -2(X_2 - X_C^0) & -2(Y_2 - Y_C^0) & -2r \\ \ldots & & \\ -2(X_n - X_C^0) & -2(Y_n - Y_C^0) & -2r \end{bmatrix} \tag{27a}$$

$$\underset{(n,m)}{B} = \begin{bmatrix} \frac{\partial f_1}{\partial X_1} & \frac{\partial f_1}{\partial Y_1} & 0 & 0 & 0 & 0 & \ldots. \\ 0 & 0 & \frac{\partial f_2}{\partial X_2} & \frac{\partial f_2}{\partial Y_2} & 0 & 0 & \ldots. \\ \ldots & & & & & & \\ \ldots. & & & & & & \\ \ldots.. & & & & & & \\ 0 & 0 & 0 & 0 & \ldots... & \frac{\partial f_n}{\partial X_n} & \frac{\partial f_n}{\partial Y_n} \end{bmatrix} \tag{27c}$$

$$\left.\begin{aligned} \frac{\partial f_1}{\partial x_1} &= 2\left(x_1 - x_c^0\right) \\ \frac{\partial f_1}{\partial y_1} &= 2\left(y_1 - y_c^o\right) \end{aligned}\right\} 1st\ row of\ the\ B\ matrix$$

Vector V – is the vector of residual of observations

In this model the weight matrix W will have the dimension (m, m) or in other words has dimensions (2n, 2n) and has the form:

$$\underset{(m,m)}{W} = \begin{bmatrix} \frac{1_1}{(\partial X_1)^2} & 0 & 0 & 0 & 0 & 0 & \ldots. \\ 0 & \frac{1}{(\partial Y_1)^2} & 0 & 0 & \ldots. & & \\ \ldots & & & & & & \\ \ldots. & & & & & & \\ \ldots.. & & & & & & \\ 0 & 0 & 0 & 0 & \ldots... & 0 & \frac{1}{(\partial Y_n)^2} \end{bmatrix} \tag{28}$$

Then, a of least squares solution is performed to find the corrected values of radius, coordinates of center, their accuracy and the distortion of the tank shell

RESULTS AND DISCUSSIONS

By using the presented technique of calculating radius and coordinates of circular section center, the values of radii and coordinates of center point and distortions of Tank 9 at Forcados Terminal were determined at three oil levels from three epochs of observations using MATLAB program. The results are presented in tables 2 and 3 below.

Tables 2 – determination of radius of tanks and coordinates of their center

For tank 9

Tank Study	Tank № 9
Number of cross sections observed	One cross section at level 2.0 m from the tank base (these observations were done when the tank was full of oil level)
Number of monitoring points in circular cross section	16 points covering the whole perimeter of tank cross section

First cycle of observations at low oil level (3m) 15.02.2003			Second cycle of observations low oil level (3m) 24.08.2004			Third cycle of observations low oil level (3m) 7.10.2008		
Radius	**r, m**	38.160	Radius	**r, m**	38.169	Radius	**r, m**	38.167
	σ_r, mm	4.7		**σ_r, mm**	3.6		**σ_r, mm**	3.6
Coordinates of center	**X, m**	324772.441	Coordinates of center	**X, m**	324772.440	Coordinates of center	**X, m**	324772.528
	σ_X, mm	6.3		**σ_X, mm**	4.8		**σ_X, mm**	3.6
	Y, m	148129.013		**Y, m**	148129.028		**Y, m**	148128.996
	σ_Y, mm	6.7		**σ_Y, mm**	5.1		**σ_Y, mm**	4.8
	Diameter	**76.320m**			**76.338m**			**76.334m**
	Actual Volume	**13724.226 m^3 118693.9bbl**			**13730.700m^3 118749.8bbl**			**13729.262m^3 118737.4bbl**
	Nominal Volume	**13681.102 m^3 118320.8bbl**			**13681.102 m^3 118320.8bbl**			**13681.102 m^3 118320.8bbl**

First cycle of observations mid oil level (10m) 15.02.2003			Second cycle of observations mid oil level (10m) 24.08.2004			Third cycle of observations mid oil level (10m) 7.10.2008	
r, m	38.213	Radius	**r, m**	38.197	Radius	**r, m**	38.200
σ_r, mm	4.0		**σ_r, mm**	3.1		**σ_r, mm**	2.7
X, m	324772.436	Coordinates of center	**X, m**	324772.439	Coordinates of center	**X, m**	324772.524
σ_X, mm	5.4		**σ_X, mm**	4.2		**σ_X, mm**	3.6
Y, m	148129.011		**Y, m**	148129.007		**Y, m**	148128.998
σ_Y, mm	5.7		**σ_Y, mm**	4.5		**σ_Y, mm**	3.9
Diameter	**76.426m**			**76.394m**			**76.400m**

Actual Volume	**45874.584 m^3 396745.8bbl**			**45836.176m^3 396413.7bbl**			**45843.377m^3 396476.0bbl**
Nominal Volume	**45603.673 m^3 394402.9bbl**			**45603.673m^3 394402.9bbl**			**45603.673m^3 394402.9bbl**
First cycle of observations full oil level (19m) 15.02.2003			Second cycle of observations full oil level (19m) 24.08.2004			Third cycle of observations full oil level (19m) 7.10.2008	
r, m	38.220	Radius	**r, m**	38.230	Radius	**r, m**	38.234
σ_r, mm	3.3		**σ_r, mm**	3.7		**σ_r, mm**	2.2
X, m	324772.436	Coordinates of center	**X, m**	324772.434	Coordinates of center	**X, m**	324772.5208
σ_X, mm	4.4		**σ_X, mm**	4.9		**σ_X, mm**	3.0
Y, m	148129.013		**Y, m**	148129.018		**Y, m**	148128.999
σ_Y, mm	4.4		**σ_Y, mm**	5.2		**σ_Y, mm**	3.2
Diameter	**76.44m**			**76.460m**			**76.468m**
Actual Volume	**87193.646 m^3 754093.4bbl**			**87239.279m^3 754488bbl**			**87257.536m^3 754645.9bbl**
Nominal Volume	**86646.979 m^3 749365.5bbl**			**86646.979m^3 749365.5bbl**			**86646.979m^3 749365.5bbl**

Table 3 - Tank 9 Distortions

STUDS	2003Low mm	2003Mid mm	2003Full mm	2004Low mm	2004Mid mm	2004Full mm	2008Low mm	2008Mid mm	2008Full mm
STUD1	-87.492	-56.672	-23.244	438.05	-13.067	458.06	-57.933	-25.136	9.6489
STUD9	-118.96	-81.888	-55.86	-4.9426	-43.617	-4.1533	-49.708	-24.706	6.9
STUD16	-74.91	-54.681	-13.414	-12.1	-10.352	14.263	-91.859	-9.7979	28.24
STUD8	-102.91	-74.732	-39.184	-6.7749	-33.592	-8.3302	-80.34	-45.213	0.8752
STUD2	-81.624	-47.132	-31.219	18.099	13.479	47.923	-59.957	-30.896	3.1295
STUD10	-119.93	-101.71	-82.46	-31.868	-66.918	-27.153	-47.711	-21.012	16.677
STUD4	-80.7	-27.692	7.9384	-15.906	-17.04	15.722	-71.06	-46.995	-2.153
STUD12	-167.47	-126	-79.96	-64.336	-108.38	-69.696	-67.424	-38.07	-2.1742
STUD3	-65.995	5.4712	24.493	23.594	12.181	49.431	-78.773	-46.509	-14.287
STUD11	-98.772	-108.43	-57.164	-32.082	-58.302	-21.456	-26.554	-1.742	33.226
STUD5	-65.727	-15.258	-0.6684	-35.492	-52.224	-22.073	-57.058	-33.602	7.2398
STUD13	-114.73	-91.798	-68.178	60.313	26.714	52.766	-59.831	-41.05	-6.615
STUD7	-21.403	0.60187	28.374	74.753	30.868	75.713	-10.013	8.9676	58.307
STUD15	-93.652	-63.679	-37.232	-8.4607	23.627	46.115	-45.482	-24.654	21.3
STUD6	-41.42	0.39721	20.854	4.2939	9.8724	55.221	-45.5	-11.735	36.221
STUD14	-70.983	-51.525	-24.8	65.465	54.179	80.974	-29.982	-10.558	38.071

The tables above are the results of the diameter of the tank and it accuracy, coordinates of the centre, and the actual volume of oil in the tank at different oil level and at three epochs of observations.

At 3m oil level in year 2003, the diameter was found to be 76.320m, while the tank nominal diameter was given as 76.20m. The crude oil volume was found to be 11869.9bbl, while the nominal volume is 118320.8bbl; this in excess of 373.1bbl, distortion was maximum at stud9 with value of 118.96mm and minimum at stud7 with a value of 21.403mm. In 2004, diameter was found to be 76.338m; oil volume 118749.8bbl, again in excess of 429bbl, distortion was maximum at stud1 with value of 438.05mm and minimum at stud9 with a value of 4.94mm. In 2008, the diameter was found to be 76.334m, actual oil volume was found to be 118737.4bbl, an oil excess of 416.6bbl, distortion was maximum at stud16 with value of 91.86mm and minimum at stud7 with a value of 10.01mm
This is an indication that there is an increase in diameter of the tank from the nominal diameter (76.2m) to 76.320 in 2003, 76.338 in 2004 and 76.334 in 2008. Also there was a corresponding increase in oil level from epoch to epoch.

When the oil volume was increased from 3m to 10m for the three epochs, the following was also deduced. In 2003, diameter was 76.426m, excess oil volume was 2342.9bbl, and distortion was maximum at stud11 with value of 108.43mm and minimum at stud6 with a value of 0.40mm. In 2004, diameter was 76.44m and excess oil volume was found to be 2010.8bbl, distortion was maximum at stud12 with value of 108.38mm and minimum at stud6 with a value of 9.87mm. In 2008, the tank diameter was found to be 76.40m while the crude oil excess was found to be 2073bbl; distortion was maximum at stud4 with value of 46.99mm and minimum at stud11 with a value of 1.74mm

Again, the oil volume was increased from 10m to 19m for the three epochs, the following was also deduced. In 2003, diameter was 76.44m, excess oil volume was 4727.9bbl, and distortion was maximum at stud10 with value of 82.46mm and minimum at stud5 with a value of 0.67mm. In 2004, diameter was 76.46m and excess oil volume was found to be 5122.5bbl, distortion was maximum at stud1 with value of 458.06mm and minimum at stud9 with a value of 4.15mm In 2008, the tank diameter was found to be 76.468m while the crude oil excess was found to be 5280.4bbl, distortion was maximum at stud16 with value of 28.24mm and minimum at stud8 with a value of 0.88mm

The diameter was computed from the radius and compared with the nominal diameter at 19m oil level. For 2003 epoch, there is an expansion of 0.24m, in 2004 the expansion was found to be 0.26m and for 2008 the expansion was found to be 0.268m. From the above result, i.e. the determined diameter, actual oil volume and coordinates of center of tank no. 9, it can be seen that there are a clear difference in these values between each epoch of observations and the nominal volume and diameter. This we mean that there has been deformation in the wall of the tank since after their construction.

CONCLUSIONS

Monitoring of tanks and tanks wall helps in identifying and quantifying deteriorations which may lead to tank failure. The history of tank disaster throughout the world reveals that problems often arise undetected due to inaccurate evaluation of the tank defects.
For an effective tank monitoring programme, the equipment used for the monitoring must be precise and of the highest quality. The monitoring personnel must be experienced in not only data capture but also the analysis of the acquired data. The period of observation should be every year and consistent throughout the life of the tank
Further studies should be carried out on the tank to ascertain the character of the tank over the years. The use of the mathematical model and associated designed MATLAB program to determine the radius and coordinates of center of circular oil tanks from geodetic data especially during the process of monitoring the structural deformation was found to be very correct and economical. The period of observation should be every year and consistent throughout the life of the tank. The results obtained in this study may however be acceptable to the structural Engineer depending on the tank specifications and its properties at the design stage.

REFERENCES

Allan, A.L. 1988. The Principles of Theodolite Intersection Systems A. L. Allan Survey Review. 226-234.

Ashraf A. Beshr (2010), Development and Innovation of Technologies for Deformation Monitoring of Engineering Structures Using Highly Accurate Modern Surveying Techniques and Instruments, Ph.D. thesis, Siberian State Academy of geodesy SSGA, Novosibirsk, Russia, 205 p. [Russian language].

Behairy, A. M. 1991. Journal of engineering faculty, Shobra, Zagazig university. – Egypt. 57- 68.

Ehigiator-Irughe, R. Environmental safety and monitoring of crude oil storage tanks at the Forcados terminal, 2005. M.Eng Thesis, Department of civil Engineering, university of Benin, Benin City. Nigeria.

Gairns, C. 2008. Development of semi-automated system for structural deformation monitoring using a reflectorless total station. M.Sc. Thesis. – Department of Geodesy and Geomatics Engineering – University of New Brunswick.