DETERMINING THE DEFORMATION VALUES USING STRUCTURAL DATA ERROR ANALYSIS

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The main purpose of structural deformation monitoring scheme and analysis is to detect any significant movements of the structure. An effective approach is to model the structure by using well-chosen discrete points located on the surface of the structure which, when situated correctly will, accurately depict the characteristics of the structure. It can then be said that any movements of those points represent deformations of the object. Large, aboveground oil storage tanks that are commonly used in oil and gas industries are examples of structures that must be routinely surveyed to monitor their stability and overall integrity. This paper describes the procedure of geodetic monitoring system of circular oil storage tanks and presents the analysis of the resulted observations to determine the values of their deformation.

KEY WORDS: STORAGE TANK, STRUCTURAL DEFORMATION, MONITORING, ANALYSIS

1.0 INTRODUCTION

As a result of tanks age, geological formation of the soil around Forcados tanks non uniform settlement of tanks foundations, loading and offloading of oil and temperature of the crude will cause stress and strain for tanks membrane and settlement of sediments. The tanks tend to undergo radial deformation or out of roundness, therefor monitoring the structural deformation of these circular oil storage tanks must be done by using accurate geodetic observations and analysis methods [1].

2.0 Deformation analysis using structural data error

The first step in statistical test is forming the vector of the coordinate differences at two different points of time t_k and t_{k+1}, and its cofactor matrix. Point displacements Δ_J are calculated by differencing the adjusted coordinates of this point J for the most recent survey campaign ($k+1$), from the coordinates obtained at reference time (k), as following [2]:

$$\Delta_J = \begin{bmatrix} X_J^{(K+1)} - X_J^{(K)} \\ Y_J^{(K+1)} - Y_J^{(K)} \\ Z_J^{(K+1)} - Z_J^{(K)} \end{bmatrix} = \begin{bmatrix} \Delta X_J \\ \Delta Y_J \\ \Delta Z_J \end{bmatrix}, \tag{1}$$

where $X_J^{K+1}, Y_J^{K+1}, Z_J^{K+1}$ – are the coordinates of point J at time t_{k+1}; X_J^K, Y_J^K, Z_J^K – coordinates of point J at time t_k; K=1,2,…,m (m – the number of cycles of observations); J =1,2,…,n (n – the number of the monitoring points on the outer surface of the tank).

The vector of root-mean-square error (RMSE) of the coordinate differences can be calculated by using the matrix form as following:

$$m_{\Delta J}^2 = \begin{bmatrix} m_{\Delta XJ}^2 & m_{XY^{K+1}}^2 + m_{XY^K}^2 & m_{XZ^{K+1}}^2 + m_{XZ^K}^2 \\ m_{YX^{K+1}}^2 + m_{YX^K}^2 & m_{\Delta YJ}^2 & m_{YZ^{K+1}}^2 + m_{YZ^K}^2 \\ m_{ZX^{K+1}}^2 + m_{ZX^K}^2 & m_{ZY^{K+1}}^2 + m_{ZY^K}^2 & m_{\Delta ZJ}^2 \end{bmatrix}$$

$$= \begin{bmatrix} m_{XJ^{K+1}}^2 + m_{XJ^K}^2 & m_{XY^{K+1}}^2 + m_{XY^K}^2 & m_{XZ^{K+1}}^2 + m_{XZ^K}^2 \\ m_{YX^{K+1}}^2 + m_{YX^K}^2 & m_{YJ^{K+1}}^2 + m_{YJ^K}^2 & m_{YZ^{K+1}}^2 + m_{YZ^K}^2 \\ m_{ZX^{K+1}}^2 + m_{ZX^K}^2 & m_{ZY^{K+1}}^2 + m_{ZY^K}^2 & m_{ZJ^{K+1}}^2 + m_{ZJ^K}^2 \end{bmatrix} \tag{2}$$

where $m_{X_J^{K+1}}, m_{Y_J^{K+1}}, m_{Z_J^{K+1}}$ – the accuracy of coordinates of point J at time t_{k+1}; $m_{X_J^K}, m_{Y_J^K}, m_{Z_J^K}$ – the accuracy of coordinates of point J at time t_k.

Point displacements Δ_J is calculated as mentioned above as the difference between the adjusted coordinates of point J the most recent survey campaign ($k+1$), and the coordinates obtained at reference time (k) by using equation (1) [3].

Comparison of the magnitude of the calculated displacement and its associated survey accuracy indicates whether the reported movement is more likely due to survey error [4].

$$|D_J| < (E_J)$$

Where D_J - the magnitude of the displacement for point J, which can be calculated as follows:

$$|D_J| = \sqrt{(X_J^{k+1} - X_J^{k})^2 + (Y_J^{k+1} - Y_J^{k})^2 + (Z_J^{k+1} - Z_J^{k})^2} \qquad (3)$$

But E_J - the maximum dimension of combined 95% confidence ellipse for radius, it can be calculated as following:

$$E_J = 1.96 \sqrt{(m_{\Delta_J}^{K+1})^2 + (m_{\Delta_J}^{K})^2} \qquad (4)$$

where $m_{\Delta_J}^{K+1}$ - RMSE in position for the most recent survey; $m_{\Delta_J}^{K}$ - RMSE in position for the (initial) or reference survey.

Then if $|D_J| < E_J$ – the point said to be stable; else $|D_J| > E_J$ – the point is moved [4].

The resulting coordinates of monitoring points must be converted into meaningful engineering values by using the suggested analysis method [5]. Point displacements in horizontal and vertical components are calculated individually by differencing the adjusted coordinates between two epochs as presented below [6].

Table 1- Comparison the magnitude of the calculated coordinate differences and its associated surveying accuracy for tank № 2 (in the period from February 2003 till August 2004)

Table 1- horizontal and vertical displacement for Tank № 2

Point	For horizontal components					For vertical component		
	ΔX_J mm	ΔY_J mm	$\sqrt{\Delta X_J^2 + \Delta Y_J^2}$ mm	$E_J^{horiz.} = 1.96\sqrt{m^2_{\Delta X_J^2} + m^2_{\Delta Y_J^2}}$ mm	Movement or not	ΔZ_J mm	$E_J^{ver.} = 1.96\sqrt{m^2_{\Delta Z_J^2}}$ mm	Movement or not
STUD 6	-16	-65	66.94	7.46	Yes	12.03	3.83	Yes
STUD 16	27	20	33.60	10.00	Yes	2.88	4.92	Yes
STUD 7	-96	-56	111.14	7.20	Yes	30.64	4.29	Yes
STUD 17	14	0	14.00	10.00	Yes	5.00	4.93	Yes
STUD 8	14	-1	14.04	8.29	Yes	30.88	2.11	Yes
STUD 18	24	16	28.84	9.94	Yes	5.54	4.81	Yes
STUD 9	-26	-19	32.20	8.61	Yes	28.45	2.16	Yes
STUD 19	-27	-11	29.15	9.81	Yes	7.33	4.58	Yes
STUD 10	14	-5	14.87	8.87	Yes	24.38	2.67	Yes
STUD 20	31	5	31.40	9.62	Yes	0.96	4.24	No
STUD 11	13	-2	13.15	9.13	Yes	11.52	3.24	Yes
STUD 1	-16	10	18.87	9.40	Yes	0.06	3.81	No
STUD 12	-21	22	30.41	9.38	Yes	1.26	3.76	No
STUD 2	46	-5	46.27	9.15	Yes	12.56	3.29	Yes
STUD 13	-15	7	16.55	9.61	Yes	0.32	4.21	No
STUD 3	-20	-16	25.61	8.88	Yes	10.48	2.70	Yes
STUD 14	-14	3	14.32	9.79	Yes	3.48	4.56	Yes
STUD 4	-1	-3	3.16	8.63	No	1.13	2.20	No
STUD 15	12	16	20.00	9.93	Yes	8.89	4.79	Yes
STUD 5	6	15	16.16	8.34	Yes	4.44	2.05	Yes

Analysis of the results in table 1 show that, in this period (from February 2003 to August 2004) all the monitoring points were moved in horizontal direction except point (STUD 4) because the difference in horizontal component exceeds the expected surveying error at these points. For vertical direction, all the points were moved except points (STUD 20, STUD 1, STUD 12 and STUD 4).

In the other hand, the results for the period of February 2003 to October 2008 show that all the monitoring points on the tank surface were moved from their positions. In horizontal components the values of deformation ranged from 4.01mm to 103.94mm but in the vertical components the deformation values ranged from 0.2mm to 23.27mm. Using the same model of analysis observations for monitoring the structural deformation of oil storage tanks, the deformation values between the epochs of observations in horizontal and vertical components are calculated for oil tank № 6 and summarized in the following Table 2.

Table 2- the deformation values between all epochs of observations for oil tank № 6

Monitoring point	**Deformation values, mm**					
	Horizontal values, mm			**Vertical values, mm**		
	t= 3 years from 5/2000 to 5/2003	**t= 4.25 year from 5/2000 to 8/2004**	**t= 8 years from 5/2000 to 5/2008**	**t= 3 years from 5/2000 to 5/2003**	**t= 4.25 year from 5/2000 to 8/2004**	**t= 8 years from 5/2000 to 5/2008**
STUD1	*64.73*	*73.34*	*155.15*	*11.51*	*15.64*	*22.96*
STUD9	*80.69*	*81.22*	*118.92*	*17.47*	*30.07*	*35.43*
STUD16	*99.57*	*106.00*	*167.01*	*14.02*	*20.19*	*29.48*
STUD8	*97.87*	*74.10*	*118.58*	*12.41*	*19.55*	*28.13*
STUD2	*77.72*	*69.48*	*143.34*	*11.08*	*16.95*	*25.44*
STUD10	*0.0*	*23.81*	*49.02*	*16.81*	*29.61*	*35.66*
STUD4	*98.77*	*52.53*	*159.51*	*0.0*	*2.70*	*9.92*
STUD12	*129.86*	*131.10*	*184.86*	*16.33*	*30.34*	*35.24*
STUD3	*41.37*	*40.46*	*128.61*	*0.0*	*3.22*	*10.56*
STUD11	*0.0*	*5.97*	*37.98*	*16.81*	*30.06*	*35.75*
STUD5	*66.92*	*21.78*	*113.99*	*4.00*	*9.98*	*16.52*
STUD13	*0.0*	*-9.14*	*72.25*	*14.91*	*28.05*	*34.07*
STUD7	*132.42*	*76.34*	*174.21*	*3.91*	*9.97*	*17.57*
STUD15	*85.80*	*75.18*	*160.36*	*10.38*	*24.82*	*31.04*
STUD6	*61.21*	*40.51*	*90.84*	*3.20*	*9.31*	*16.32*
STUD14	*83.35*	*94.97*	*139.21*	*12.31*	*27.28*	*33.17*

From the resulted data presented in Table 2, it is possible to draw the relationship between the interval times of epochs of observations and the calculated values of deformation for all monitoring points.

For radius, equation (5) will have the form:

$$\left|\mathrm{D}_{\mathrm{r}}\right| = \sqrt{(r_{act.}^{k+1} - r_{act.}^{k})^2} \tag{5}$$

Where: $r_{act.}^{k+1}$ - The actual value of radius resulted from least square at time *k+1*;

$r_{act.}^{k}$ - The actual value of radius resulted from least square at time *k*.

But E_{J} - the maximum dimension of combined 95% confidence ellipse for radius, it can be calculated as following:

$$\mathrm{E}_{\mathrm{r}} = 1.96\ \sqrt{(m_r^{K+1})^2 + (m_r^{K})^2} \tag{6}$$

Where m_r^{K+1} - the standard error in position of radius for the most recent survey; m_r^K - the standard error in position of the radius for the (initial) or reference survey.

Then if $|D_r| < E_r$ – the radius isn't changed; else $|D_r| > E_r$ – the radius is changed.

5.0 ANALYSIS AND CONCLUTION

Table I gives the horizontal and vertical deformation values for tank № 6. The first epoch of observation was year 2000, this serve as the reference observation. From the above, in term of horizontal component for year 2000 and 2003, the minimum deformation was at studs 10, 11 and 13 with value zero. By this we mean that no displacement at theses monitoring point for the year under study. The maximum deformation occurred at stud 7 with numerical value of 44.14mm. For year 2000 and 2004, the minimum deformation was found to be -2.15mm at stud 13 and maximum at stud 12 with a numerical value of 30.85mm. For 200 and 2008, the minimum displacement was at stud 5 with value of 4.75mm and maximum at stud 12 with value 23.11mm.

In term of settlement, the vertical displacement for year 2000 and 2003 was minimum at studs 3 and 4 with a zero value which is an indication that there was no displacement at these monitoring points for that year. The maximum displacement occurred at stud 9 with a numerical value of 5.53mm.

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