DEFORMATION PREDICTION USING QUADRATIC POLYNOMIAL FUNCTIONS

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ABSTRACT

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, 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. By Deformation, we mean change of shape of any structure from its original shape and by monitoring over time using Geodetic means, the change in shape, size and the overall structural dynamics behaviors of structure can be detected. Prediction is therefor based on the epochs measurement obtained during monitoring, the life time, failure and danger period of the structured may be forecast. The main purpose of structural deformation monitoring scheme and analysis is to detect any significant movements of the structure.The knowledge of behaviour of Tank Structure under uniaxial/biaxial tensile loads is necessary to predict the changes in perform geometry of the structure.. The aim of this study is to predict the Deformation experience by the structure under continuous loading with data obtained in four epochs of measurement using Quadratic polynomial technique. The predictions are compared with measured data reported in literature and the results are discussed. The computational aspects of implementation of the model are also discussed briefly.

KEY WORDS: STRUCTURAL DEFORMATION, KINEMATIC, KALMAN FILTER,

1.0 INTRODUCTION

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.[1] 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 [2].

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.

The surveillance of an object involved in a deformation process requires the object as well as modeling process. Geodetic modeling of object and its surrounding means dissecting the continuum by discrete points in such a way that the points characterize the object, and that the movements of the points represent the movements and distortions of the object. This means that only the geometry of the object is modeled. Furthermore, modeling the deformation process means conventionally to observe (by geodetic method) the characteristic points in certain time intervals in order to monitor properly the temporal course of the movements. This means that only the temporal aspect of the process is modeled [2].

2.0 Prediction of the deformation values of circular oil storage tanks

One of the main topics in monitoring structural deformation is the prediction of the deformation values. Time of observations for the purpose of structural deformation and the frequency of cycles can vary from a few hours, days to several months or even years. It is important that not only determining the changes in the structure but also these changes have statistics on which to make predictions for the future, which will help to avoid accidents.

Deformation structures can be fully determined by the movement of points which are measured on the construction. Let the vector position of point P in three-dimensional coordinate system (X, Y, Z) before and after deformation is equal to r_p and $r^{/}_p$ respectively. Then $r^{/}_p$ may be expressed as [4]:

$$r_P^{/} = f(x_p, y_p, z_p, t), \tag{1}$$

where t - time variation between two cycles (epochs) of observations.

From equation (1) the displacement of the observed point depends on their initial position and time. The displacement vector dp at the point P is defined as:

$$d_P = r_P^{/} - r_P = f((x_p - x_0),(y_p - y_0),(z_p - z_0),(t - t_0)) \tag{2}$$

In this work we presented some functions to predict the deformation values of monitoring points on the outer surface of the studied oil storage tank.

3.0 Quadratic polynomial function

The mathematical model of quadratic polynomial function for three-dimensional coordinate system for the purpose of monitoring structural deformation represented as follows [5]:

$$\begin{bmatrix} \Delta X_J^i \\ \Delta Y_J^i \\ \Delta Z_J^i \end{bmatrix} = a\ \Delta t_i^2 + b\ \Delta t_i\ + c, \tag{3}$$

:

To determine the coefficients a, b for each monitoring point, least square theory must be used. The observation least square has the following matrix form:

$$\mathbf{A}_{(3\,m,\,2)}\,\mathbf{X}_{(2,1)} + \mathbf{L}_{(3\,m,\,1)} = \mathbf{V}_{(\,3\,m,1)}\,. \tag{4}$$

Where m – the number of epochs of observations.

Matrix **A** will be determined by differentiation the equation with respect to parameters a, b. By least square estimation and using equation (4), the matrix A will have the form and has the form [6]:

$$\underset{(3m,3)}{A} = \begin{bmatrix} \Delta t_1^2 & \Delta t_1 & 1 \\ \Delta t_1^2 & \Delta t_1 & 1 \\ \Delta t_1^2 & \Delta t_1 & 1 \\ \Delta t_2^2 & \Delta t_2 & 1 \\ \Delta t_2^2 & \Delta t_2 & 1 \\ \Delta t_2^2 & \Delta t_2 & 1 \\ \Delta t_3^2 & \Delta t_3 & 1 \\ \ldots & & \\ \Delta t_m^2 & \Delta t_m & 1 \end{bmatrix}, \quad \mathrm{L} = \begin{bmatrix} \Delta h_1 \\ \Delta h_2 \\ \Delta h_3 \\ \Delta h_4 \\ \Delta h_5 \\ \Delta h_6 \\ \Delta h_7 \\ \Delta h_8 \\ \Delta h_9 \\ \ldots\ldots \\ \Delta h_m \end{bmatrix} \tag{5}$$

The least square solution for the three parameters a, b, c and its accuracy are presented in equation (6) and (7) respectively.

$$\begin{bmatrix} \bar{a} \\ \bar{b} \\ \bar{c} \end{bmatrix} = (A^T\ A)^{-1}\ (A^T\ L)\ . \qquad (6)$$

$$\begin{bmatrix} m_a^2 & m_{ab} & m_{ac} \\ m_{ba} & m_b^2 & m_{bc} \\ m_{ca} & m_{cb} & m_c^2 \end{bmatrix} = (A^T\ A)^{-1}. \qquad (7)$$

The normal equation given by:

$$n = a^T .a \qquad (8)$$

The solution of the normal equation is given as

$$\mathbf{n} = \begin{pmatrix} 4503.253906 & 615.765625 & 91.0625 \\ 615.765625 & 91.0625 & 15.25 \\ 91.0625 & 15.25 & 3 \end{pmatrix}$$

Table - 1: Deformation Value

Monitoring point	Velocity, mm/year Vertical values, mm/year 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 May-08
STUD1	*3.84*	*3.68*	*2.87*
STUD9	*5.82*	*7.08*	*4.43*
STUD16	*4.67*	*4.75*	*3.69*
STUD8	*4.14*	*4.6*	*3.52*
STUD2	*3.69*	*3.99*	*3.18*
STUD10	*5.6*	*6.97*	*4.46*
STUD4	*0*	*0.64*	*1.24*
STUD12	*5.44*	*7.14*	*4.41*
STUD3	*0*	*0.76*	*1.32*
STUD11	*5.6*	*7.07*	*4.47*
STUD5	*1.33*	*2.35*	*2.07*
STUD13	*4.97*	*6.6*	*4.26*
STUD7	*1.3*	*2.35*	*2.2*
STUD15	*3.46*	*5.84*	*3.88*
STUD6	*1.07*	*2.19*	*2.04*
STUD14	*4.1*	*6.42*	*4.15*

Using equation (6), the value of the unknown can be computed using Mathcad and the result is presented thus;

$$\mathbf{x1} = \begin{pmatrix} -0.069333 \\ 0.566667 \\ 3.594 \end{pmatrix}$$

The inverse of the normal equation is given as:

$$\mathbf{n}^{-1} = \begin{pmatrix} 0.073956 & -0.834844 & 1.998933 \\ -0.834844 & 9.497956 & -22.940267 \\ 1.998933 & -22.940267 & 56.2704 \end{pmatrix}$$

From equation (7), the accuracy of the model is:

$$\mathbf{sega} := \sqrt{\mathbf{qx}_{(0,0)}} \qquad \mathbf{segb} := \sqrt{\mathbf{qx}_{(1,1)}} \qquad \mathbf{segc} := \sqrt{\mathbf{qx}_{(2,2)}}$$

Seg(a) = 0.271948mm
Seg(b) = 3.081875mm
Seg(c) = 7.501360mm

Below is the graph of prediction plotted time against deformation values for tank 6 stud 16

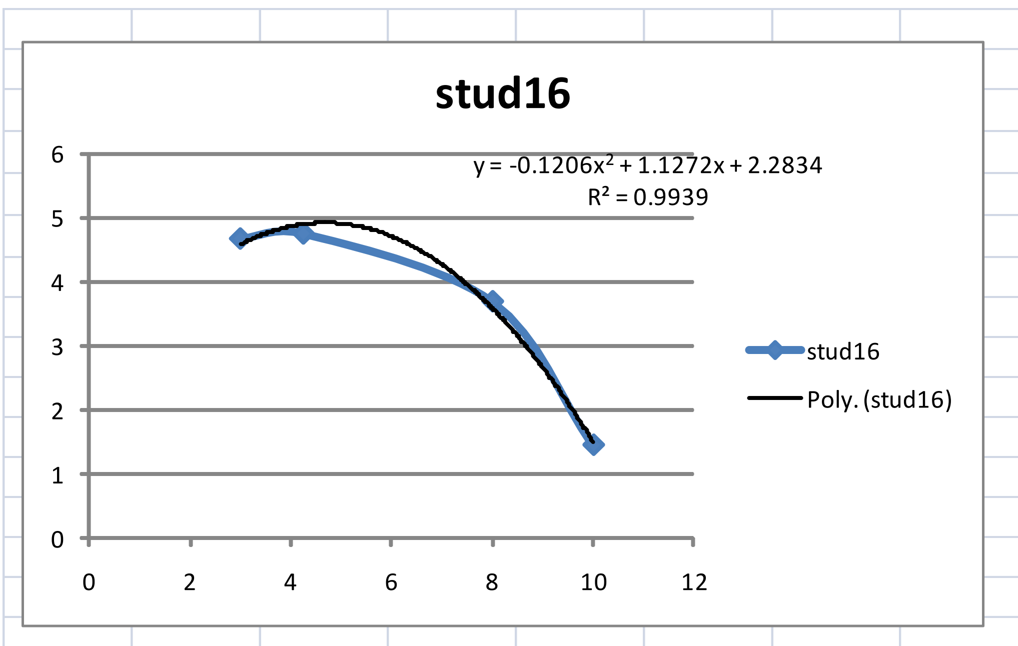

Figure: 1.0 - Plot of Velocity against time for Stud 16

4.0 ANALYSIS OF RESULTS AND CONCLUSION

Table 1 shows vertical deformation values while fig 1.0 is the plot of time against velocity for monitoring point stud 16 for tank № 6. From the above, the predicted deformation graph and the observed value intersected at two points with time 4yr with a velocity of 4mm/yr and time 3.2yr with velocity of 8mm/yr respectively.

At time equal to 3.3yr with velocity of 8mm/yr and time equal to 1.5yr with velocity of 10mm/yr, there was a uniform slope which gives an indication that the value of deformation is uniform. Also at time equal to 4yr with Velocity equal to 4mm/yr and time equal to 3.6yr with velocity of 3mm/yr, there was also uniformity between predicted and actual observation. These two scenarios give an indication of the accuracy of the model. It is important to note that no observation was carried out in year 2001, 2002, 2005, 2006 and 2007 because of the unrest in the Niger delta of Nigeria.

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