 

# Utilization of Kalman Filter Technique in Deformation Prediction of Above Surface Storage Tank

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**Abstract**
Kalman filtering is a multiple-input, multiple-output filter that can optimally estimate the states of a system, so it can be considered a suitable means for deformation analysis. The states are all the variables needed to completely describe the system behavior of the deformation process as a function of time (such as position, velocity etc.). The standard Kalman filter estimates the state vector where the measuring process is described by a linear system. While, in order to process a non-linear system an optimized aspect of Kalman filter is appropriate. Engineering Geodesy is the application of only geodetic methods for mapping certain geometric shape or of the topographic surface with respect to accurately define reference frame. Geodetic methods configure positions in Space with respect to the Earth and interpret the geodetic measurements in terms of a Euclidean Geometry. However Geodesy as discipline may unravel not only the geometric but also the kinematical and the physical nature of the Earth via geometric measures. At present, like in other Earth disciplines, Geodesy measurements depend on the dynamical and physical features of the Earth. One of the main issues of Engineering Geodesy is accurate prediction of value of structural deformation. Above storage Tank is like other deformable structure whose shape, form and safety is of interest to Engineering fields. The main purpose of structural deformation monitoring scheme and analysis is to detect any significant movements of the structure. Presented here is geodetic methods of determination of Velocity and Acceleration of deformable object in Time domain and predict deformation value using Kalman Filter. Analysis of the result indicated that there are correlations between the observed and the predicted deformation value for year 2004, 2008, 2010 and 2012 respectively.
**Keywords**: Structural Deformation, Kinematic, Kalman Filter

## 1.0 Introduction

Deformable structures needs to be measured precisely in order to determine the structure's stability and safety. Examples are steel storage tanks used in oil industry depots. Storage steel tanks are always cylindrical in shape with different diameters and heights. The consequences of fabrication processes on steel shell buckling strength strongly influence the amplitudes and forms of its geometric imperfections. The geometric distortion in tank of cylindrical shape and tilting causing additional stresses not considered in the design on the shells forming the tank walls [4].

Monitoring surveys for deformation measurements of deformable bodies has been used for the verification of material parameters, determination of causative factors, and determination of deformation mechanisms [1]. Therefore monitoring of such geometric imperfection (out of roundness) is important for decisions concerning the structure maintenance or its liability to be in service, (API, 2003). Ground.

One of the main topics in Engineering Geodesy is monitoring structural deformation and the prediction of the deformation values based on Time or frequency domain or both. 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 we not only determine the changes in the structure but also these changes have statistics on which to make predictions for the future, which will help to prevent disaster [2].

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

## 2.0 Structural Deformation Modeling

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

$$r'_P = f(x_p, y_p, z_p, t), \qquad (1)$$

where t is the 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:

$$d_p = r_p^{/} - r_p = f(x_p - x_0),(y_p - y_0),(z_p - z_0),(t_p - t_0)) \qquad (2)$$

Nowadays, different models have been developed for analysis and the interpretation of structural deformations. These models include static, kinematic and dynamic models. Static model is not time dependent but provides the deformation characteristic on points, area or the structure being monitored.
However, most of the current engineering applications require monitoring of movement behaviors. A kinematic deformation model determines displacements, velocities and acceleration and is time dependent.
In dynamic model, in addition to the kinematic model, the relationship between deformations and the influencing factors are also taken into consideration. Different deformation analysis algorithms are shown in (fig. 1.0).

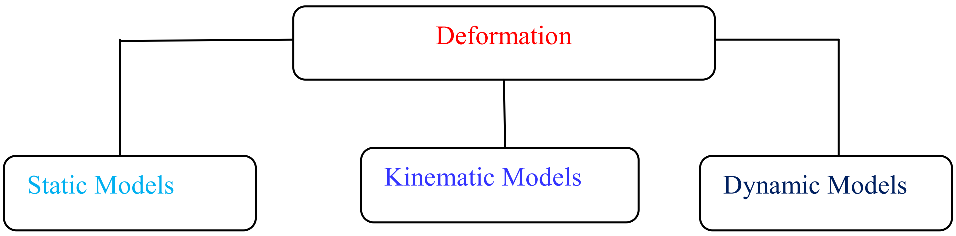


Figure 1.0 - Hierarchy of models in geodetic deformation analysis

In the following table (fig. 2.0), the three categories of deformation models are characterized by their capacity of taking the factors 'time' and 'load' into account.

| Deformation Model | Static Model | Kinematic Model | Dynamic Model |
|---|---|---|---|
| Time | No modeling | Movement as a function of time | Movement as a function of time and loads |
| Acting Forces | Displacement as a function of load | No model | |
| State of the object | Sufficiently in equilibrium under loads | Permanently in motion | Permanently in motion |

Figure 2.0 - Characterization and classification of deformation models

### 3.0 Structural deformation analysis using Kinematic model

When automated measurement procedures came into use, the temporal course of deformation processes was more considered in models evaluation. If these models are restricted to the investigation and description of object movements and distortions in space and time, one speaks of kinematic models which have offered the opportunity to extend the classical purely geometrical deformation analysis in congruence models.
Kinematic models allow estimating the velocity and even the acceleration (by building double differences) of control point movements. Because this is done for every single point, this type of models is called "single point" deformation models. The unknown parameters of a single point deformation model are the velocity and the acceleration of control points. Therefore, a time-dependent function is required to estimate these parameters. In this paper we are only considering the velocity model.

The intention of kinematic models is to find a suitable description of point movements by time functions without regarding the potential relationship to causative forces. Polynomial approaches, especially velocities and accelerations, and harmonic functions are commonly applied.
A time-dependent 3-D kinematic model that contains position, velocity and acceleration can be expressed by the following formula:

 

$$X_j^{(k+1)} = X_j^{(k)} + (t_{k+1} - t_k)\, v_{xj} + \frac{1}{2}(t_{k+1} - t_k)^2 a_{xj}$$

$$Y_j^{(k+1)} = Y_j^{(k)} + (t_{k+1} - t_k)\, v_{yj} + \frac{1}{2}(t_{k+1} - t_k)^2 a_{yj}$$

$$Z_j^{(k+1)} = Z_j^{(k)} + (t_{k+1} - t_k)\, v_{zj} + \frac{1}{2}(t_{k+1} - t_k)^2 a_{zj} \qquad (3.0)$$

Where $X_J^{K+1}, Y_J^{K+1}, Z_J^{K+1}$ - Coordinates of point $J$ at time $t_{k+1}$ (predicted values), $v_{X_J}^K, v_{Y_J}^K, v_{Z_J}^K$ – velocities of X, Y,Z coordinates of point $J$ at time $t_k$; $a_{X_J}^K, a_{Y_J}^K, a_{Z_J}^K$ – accelerations of X, Y,Z coordinates of point $J$ at time $t_k$. k=1, 2, . . . , m (m: measurement period number( number of epochs)). j =1, 2, n (n: number of points).

## 4.0 Kalman Filtering Model

Kalman filtering is an important tool for deformation analysis combining information on object behavior and measurement quantities. The intention of kinematic models is to find a suitable description of point movements by time functions without regarding the potential relationship to causative forces.
Kalman filtering technique is employed for the prediction of present state vector using state vector information of known motion parameters at period $t_k$ and the measurements collected at period $t_{k+1}$. The state vector of motion parameters consists of position, motion and acceleration variables. The motion and acceleration parameters are the first and the second derivations of the position with respect to time. The matrix form of the motion model used for the prediction of motion parameters by Kalman filtering technique in 3-D networks can be given as follows:

$$\begin{bmatrix} X_J^{K+1} \\ Y_J^{K+1} \\ Z_J^{K+1} \end{bmatrix} = \begin{bmatrix} X_J^{K} \\ Y_J^{K} \\ Z_J^{K} \end{bmatrix} + (t_{K+1} - t_K) \begin{bmatrix} v_{X_J}^{K} \\ v_{Y_J}^{K} \\ v_{Z_J}^{K} \end{bmatrix} + \frac{1}{2}(t_{K+1} - t_K)^2 \begin{bmatrix} a_{X_J}^{K} \\ a_{Y_J}^{K} \\ a_{Z_J}^{K} \end{bmatrix}, \qquad (3.1)$$

By analysis of equation (2.0) it is shown that the unknown displacement parameters consist of position, velocity (first derivative of position) and acceleration (second derivative of position). These unknown parameters can be calculated using the method of Kalman filter with four cycles of measurements at different times.
Kalman Filter is designed for recursive estimation to the state vector of a priori known dynamical system. To determine the current state of the system, the current measurement must be known, as well as the previous state of the filter. Thus, the Kalman filter is implemented in the time representation, rather than in frequency. Using the Kalman filter, the kinematic model of movement of any observable point J on the surface of circular oil storage tanks can be written in form as following which represent the Velocity and acceleration of the structure. The velocity is presented thus:

$$\left.\begin{aligned} v_{X_J}^{K+1} &= \frac{X_J^{K+1} - X_J^K}{\Delta t_{k+1,k}}; \\ v_{Y_J}^{K+1} &= \frac{Y_J^{K+1} - Y_J^K}{\Delta t_{k+1,k}}; \\ v_{Z_J}^{K+1} &= \frac{Z_J^{K+1} - Z_J^K}{\Delta t_{k+1,k}}. \end{aligned}\right\} \qquad (4.0)$$

And the acceleration by the form:

$$\left.\begin{aligned} a_{X_J}^{K+1} &= \frac{X_J^{K+1} - X_J^K}{\Delta t_{k+1,k}^2}; \\ a_{Y_J}^{K+1} &= \frac{Y_J^{K+1} - Y_J^K}{\Delta t_{k+1,k}^2}; \\ a_{Z_J}^{K+1} &= \frac{Z_J^{K+1} - Z_J^K}{\Delta t_{k+1,k}^2}. \end{aligned}\right\} \quad (5.0)$$

The derived values of displacement, velocities and acceleration are presented below.

Table 1: Velocity and Acceleration

| 2003 Measurement for Tank2 | | | 2004 Measurement for Tank2 | | | | Displacement | | | Velocity | | | Acceleration | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | North1 | East1 | Elev1. | North2 | East2 | Elev2. | ΔN | ΔE | ΔH | X | Y | Z | X | Y | Z |
| STUD 6 | 148688.5 | 325131.7 | 3.60587 | 148688.5 | 325131.7 | 3.6179 | 0.042 | 0.016 | -0.01203 | 0.02625 | 0.01 | -0.00752 | 0.01640625 | 0.00625 | -0.0047 |
| STUD 16 | 148706 | 325057.3 | 3.61115 | 148706 | 325057.3 | 3.61403 | -0.02 | -0.027 | -0.00288 | -0.0125 | -0.016875 | -0.0018 | -0.0078125 | -0.0105469 | -0.00113 |
| STUD 7 | 148677.5 | 325127.2 | 3.59841 | 148677.4 | 325127.1 | 3.62905 | 0.056 | 0.096 | -0.03064 | 0.035 | 0.06 | -0.01915 | 0.021875 | 0.0375 | -0.01197 |
| STUD 17 | 148717.3 | 325061.9 | 3.60792 | 148717.3 | 325061.9 | 3.61292 | 0 | -0.014 | -0.005 | 0 | -0.00875 | -0.00312 | 0 | -0.0054688 | -0.00195 |
| STUD 8 | 148668.6 | 325119.6 | 3.60042 | 148668.6 | 325119.6 | 3.6313 | 0.001 | -0.014 | -0.03088 | 0.000625 | -0.00875 | -0.0193 | 0.000390625 | -0.0054687 | -0.01206 |
| STUD 18 | 148726.4 | 325069.7 | 3.61154 | 148726.4 | 325069.7 | 3.606 | -0.016 | -0.024 | 0.00554 | -0.01 | -0.015 | 0.003463 | -0.00625 | -0.009375 | 0.002164 |
| STUD 9 | 148662.1 | 325109.2 | 3.59636 | 148662.1 | 325109.2 | 3.62481 | 0.019 | 0.026 | -0.02845 | 0.011875 | 0.01625 | -0.01778 | 0.007421875 | 0.0101563 | -0.01111 |
| STUD 19 | 148732.6 | 325079.9 | 3.61372 | 148732.6 | 325079.8 | 3.60639 | 0.011 | 0.027 | 0.00733 | 0.006875 | 0.016875 | 0.004581 | 0.004296875 | 0.0105469 | 0.002863 |
| STUD 10 | 148659.3 | 325097.5 | 3.59555 | 148659.3 | 325097.5 | 3.61993 | 0.005 | -0.014 | -0.02438 | 0.003125 | -0.00875 | -0.01524 | 0.001953125 | -0.0054688 | -0.00952 |
| STUD 20 | 148735.4 | 325091.5 | 3.61362 | 148735.4 | 325091.5 | 3.61266 | -0.005 | -0.031 | 0.00096 | -0.003125 | -0.019375 | 0.0006 | -0.001953125 | -0.0121094 | 0.000375 |
| STUD 11 | 148660.2 | 325085.6 | 3.60498 | 148660.2 | 325085.6 | 3.6165 | 0.002 | -0.013 | -0.01152 | 0.00125 | -0.008125 | -0.0072 | 0.00078125 | -0.0050781 | -0.0045 |
| STUD 1 | 148734.5 | 325103.3 | 3.61026 | 148734.5 | 325103.3 | 3.6102 | -0.01 | 0.016 | 6E-05 | -0.00625 | 0.01 | 3.75E-05 | -0.00390625 | 0.00625 | 2.34E-05 |
| STUD 12 | 148664.8 | 325074.6 | 3.60422 | 148664.8 | 325074.5 | 3.60548 | -0.022 | 0.021 | -0.00126 | -0.01375 | 0.013125 | -0.00079 | -0.00859375 | 0.0082031 | -0.00049 |
| STUD 2 | 148729.9 | 325114.4 | 3.62013 | 148729.9 | 325114.5 | 3.60757 | 0.005 | -0.046 | 0.01256 | 0.003125 | -0.02875 | 0.00785 | 0.001953125 | -0.0179687 | 0.004906 |
| STUD 13 | 148672.5 | 325065.5 | 3.60758 | 148672.5 | 325065.5 | 3.6079 | -0.007 | 0.015 | -0.00032 | -0.004375 | 0.009375 | -0.0002 | -0.002734375 | 0.0058594 | -0.00012 |
| STUD 3 | 148721.8 | 325123.9 | 3.62297 | 148721.8 | 325123.8 | 3.61249 | 0.016 | 0.02 | 0.01048 | 0.01 | 0.0125 | 0.00655 | 0.00625 | 0.0078125 | 0.004094 |
| STUD 14 | 148682.7 | 325059.3 | 3.60677 | 148682.7 | 325059.2 | 3.60329 | -0.003 | 0.014 | 0.00348 | -0.001875 | 0.00875 | 0.002175 | -0.001171875 | 0.0054688 | 0.001359 |
| STUD 4 | 148712 | 325129.8 | 3.61645 | 148712 | 325129.8 | 3.61532 | 0.003 | 0.001 | 0.00113 | 0.001875 | 0.000625 | 0.000706 | 0.001171875 | 0.0003906 | 0.000441 |
| STUD 15 | 148694.3 | 325056.5 | 3.61244 | 148694.3 | 325056.5 | 3.60355 | -0.016 | -0.012 | 0.00889 | -0.01 | -0.0075 | 0.005556 | -0.00625 | -0.0046875 | 0.003473 |
| STUD 5 | 148700.4 | 325132.6 | 3.61094 | 148700.4 | 325132.6 | 3.61538 | -0.015 | -0.006 | -0.00444 | -0.009375 | -0.00375 | -0.00278 | -0.005859375 | -0.0023437 | -0.00173 |

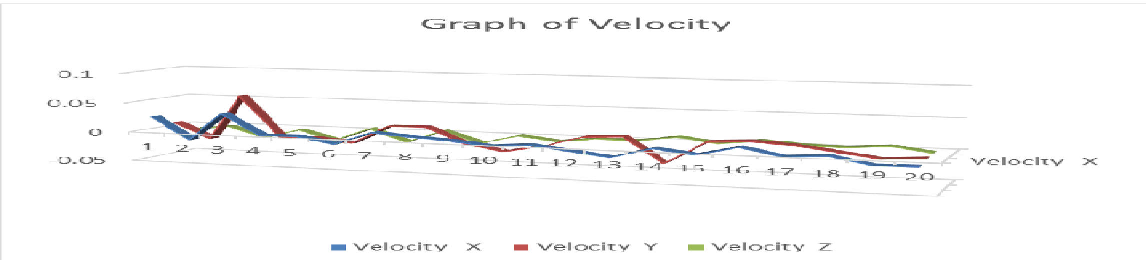


Figure 3: Graph of velocity

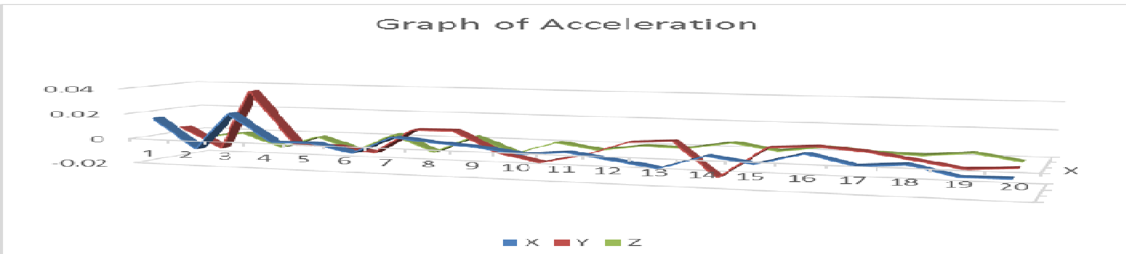


Figure 4: Graph of Acceleration

Table 2: Prediction

| Prediction for 2005 | | | Prediction for 2007 | | | Prediction for 2008 | | | Measured 2008 | | | Prediction for 2012 | | | Measured 2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | Y | Z | X | Y | Z | X | Y | Z | X | Y | Z | X | Y | Z | X | Y | Z |
| 148688.6792 | 325131.8 | 3.554555 | 148688.807 | 325131.807 | 3.517901 | 148689 | 325131.9 | 3.46151 | 148688.5 | 325131.6 | 3.61339 | 148690 | 325132.3 | 3.175797 | 148688.5 | 325131.68 | 3.5738052 |
| 148705.8947 | 325057.2 | 3.609969 | 148705.834 | 325057.123 | 3.59009 | 148705.7 | 325057 | 3.57659 | 148706.1 | 325057.2 | 3.59857 | 148705.3 | 325056.4 | 3.599619 | 148706 | 325057.401 | 3.595498 |
| 148677.6989 | 325127.6 | 3.585843 | 148677.87 | 325127.902 | 3.374355 | 148678.1 | 325128.4 | 3.23073 | 148688.5 | 325127.1 | 3.6166 | 148679.5 | 325130.6 | 3.47573 | 148677.4 | 325127.094 | 3.588741 |
| 148717.25 | 325061.9 | 3.605869 | 148717.25 | 325061.818 | 3.571358 | 148717.3 | 325061.8 | 3.54792 | 148706.1 | 325061.9 | 3.59228 | 148717.3 | 325061.4 | 3.5879 | 148717.3 | 325061.925 | 3.598913 |
| 148668.5643 | 325119.5 | 3.587754 | 148668.567 | 325119.488 | 3.37461 | 148668.6 | 325119.4 | 3.22986 | 148668.6 | 325119.6 | 3.60884 | 148668.6 | 325119.1 | 3.476779 | 148668.6 | 325119.601 | 3.594216 |
| 148726.2918 | 325069.6 | 3.613812 | 148726.243 | 325069.515 | 3.652051 | 148726.2 | 325069.4 | 3.67802 | 148726.4 | 325069.6 | 3.59289 | 148725.8 | 325068.8 | 3.633722 | 148726.4 | 325069.691 | 3.595668 |
| 148662.161 | 325109.3 | 3.584691 | 148662.219 | 325109.38 | 3.388319 | 148662.3 | 325109.5 | 3.25496 | 148662.1 | 325109.1 | 3.60301 | 148662.8 | 325110.1 | 3.482449 | 148662.1 | 325109.165 | 3.58608 |
| 148732.6269 | 325080 | 3.616726 | 148732.66 | 325080.057 | 3.667321 | 148732.7 | 325080.2 | 3.70168 | 148732.6 | 325079.8 | 3.60024 | 148733 | 325080.8 | 3.643069 | 148732.6 | 325079.833 | 3.59719 |
| 148659.3113 | 325097.4 | 3.58555 | 148659.327 | 325097.368 | 3.417271 | 148659.4 | 325097.3 | 3.30299 | 148659.3 | 325097.5 | 3.59802 | 148659.5 | 325097 | 3.497935 | 148659.3 | 325097.539 | 3.584126 |
| 148735.3687 | 325091.3 | 3.614014 | 148735.353 | 325091.233 | 3.62064 | 148735.3 | 325091.1 | 3.62514 | 148735.5 | 325091.4 | 3.59685 | 148735.2 | 325090.4 | 3.617464 | 148735.4 | 325091.497 | 3.606099 |
| 148660.2485 | 325085.5 | 3.600255 | 148660.255 | 325085.495 | 3.52074 | 148660.3 | 325085.4 | 3.46674 | 148660.3 | 325085.6 | 3.58834 | 148660.3 | 325085.1 | 3.558855 | 148660.2 | 325085.652 | 3.578261 |
| 148734.4473 | 325103.4 | 3.610285 | 148734.417 | 325103.437 | 3.610699 | 148734.4 | 325103.5 | 3.61098 | 148734.6 | 325103.3 | 3.59685 | 148734.1 | 325103.9 | 3.6105 | 148734.5 | 325103.18 | 3.603854 |
| 148664.6962 | 325074.6 | 3.603703 | 148664.629 | 325074.714 | 3.595006 | 148664.5 | 325074.8 | 3.5891 | 148664.8 | 325074.5 | 3.58973 | 148664 | 325075.3 | 3.599175 | 148664.8 | 325074.571 | 3.573557 |
| 148729.9513 | 325114.2 | 3.625282 | 148729.967 | 325114.104 | 3.711975 | 148730 | 325113.9 | 3.77085 | 148730 | 325114.4 | 3.59457 | 148730.1 | 325112.8 | 3.670419 | 148734.5 | 325103.18 | 3.603854 |
| 148672.5001 | 325065.6 | 3.607449 | 148672.479 | 325065.6 | 3.60524 | 148672.4 | 325065.7 | 3.60374 | 148672.6 | 325065.4 | 3.58607 | 148672.3 | 325066 | 3.606299 | 148672.5 | 325065.504 | 3.579412 |
| 148721.8783 | 325123.9 | 3.627268 | 148721.927 | 325124.006 | 3.699605 | 148722 | 325124.1 | 3.74873 | 148721.9 | 325123.8 | 3.59854 | 148722.4 | 325124.6 | 3.664931 | 148721.8 | 325123.818 | 3.612364 |
| 148682.7072 | 325059.3 | 3.608197 | 148682.698 | 325059.352 | 3.632218 | 148682.7 | 325059.4 | 3.64853 | 148682.8 | 325059.2 | 3.58672 | 148682.6 | 325059.8 | 3.620704 | 148682.7 | 325059.25 | 3.578297 |
| 148711.9728 | 325129.8 | 3.616913 | 148711.982 | 325129.777 | 3.624713 | 148712 | 325129.8 | 3.63001 | 148712 | 325129.7 | 3.60084 | 148712.1 | 325129.8 | 3.620974 | 148712 | 325129.769 | 3.61904 |
| 148694.2218 | 325056.4 | 3.616086 | 148694.173 | 325056.362 | 3.677448 | 148694.1 | 325056.3 | 3.71912 | 148694.4 | 325056.3 | 3.59913 | 148693.7 | 325056 | 3.648035 | 148694.3 | 325056.45 | 3.583622 |
| 148700.316 | 325132.6 | 3.609119 | 148700.27 | 325132.536 | 3.578473 | 148700.2 | 325132.5 | 3.55766 | 148700.4 | 325132.5 | 3.60325 | 148699.8 | 325132.4 | 3.593163 | 148700.4 | 325132.566 | 3.60185 |

Table 3: Correlation

| Name | Prediction for 2008 | | | Measured 2008 | | | Correlation 2008 | | | Prediction for 2012 | | | Measured 2012 | | | Correlation 2012 | | | Resultant | Resultant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | ΔN | ΔE | ΔH | X | Y | Z | X | Y | Z | ΔN | ΔE | ΔH | r^2 for 2008 | r^2 for 2012 |
| STUD 6 | 148689 | 325131.9 | 3.46151 | 148688.5 | 325131.6 | 3.61339 | 0.497 | 0.250 | -0.152 | 148690.002 | 325132.262 | 3.176 | 148688.468 | 325131.680 | 3.574 | 1.534 | 0.582 | -0.398 | 0.577 | 1.688 |
| STUD 16 | 148705.7 | 325057 | 3.57659 | 148706.1 | 325057.2 | 3.59857 | -0.377 | -0.218 | -0.022 | 148705.265 | 325056.355 | 3.600 | 148706.010 | 325057.401 | 3.595 | -0.745 | -1.046 | 0.004 | 0.436 | 1.284 |
| STUD 7 | 148678.1 | 325128.4 | 3.23073 | 148688.5 | 325127.1 | 3.6166 | -10.375 | 1.293 | -0.386 | 148679.462 | 325130.632 | 3.476 | 148677.412 | 325127.094 | 3.589 | 2.050 | 3.538 | -0.113 | 10.462 | 4.091 |
| STUD 17 | 148717.3 | 325061.8 | 3.54792 | 148706.1 | 325061.9 | 3.59228 | 11.133 | -0.102 | -0.044 | 148717.250 | 325061.419 | 3.588 | 148717.265 | 325061.925 | 3.599 | -0.015 | -0.506 | -0.011 | 11.134 | 0.506 |
| STUD 8 | 148668.6 | 325119.4 | 3.22986 | 148668.6 | 325119.6 | 3.60884 | -0.008 | -0.128 | -0.379 | 148668.596 | 325119.090 | 3.477 | 148668.562 | 325119.601 | 3.594 | 0.034 | -0.511 | -0.117 | 0.400 | 0.526 |
| STUD 18 | 148726.2 | 325069.4 | 3.67802 | 148726.4 | 325069.6 | 3.59289 | -0.255 | -0.228 | 0.085 | 148725.788 | 325068.832 | 3.634 | 148726.358 | 325069.691 | 3.596 | -0.570 | -0.859 | 0.038 | 0.352 | 1.032 |
| STUD 9 | 148662.3 | 325109.5 | 3.25496 | 148662.1 | 325109.1 | 3.60301 | 0.212 | 0.397 | -0.348 | 148662.759 | 325110.120 | 3.482 | 148662.062 | 325109.165 | 3.586 | 0.697 | 0.955 | -0.104 | 0.569 | 1.187 |
| STUD 19 | 148732.7 | 325080.2 | 3.70168 | 148732.6 | 325079.8 | 3.60024 | 0.081 | 0.407 | 0.101 | 148732.973 | 325080.825 | 3.643 | 148732.564 | 325079.833 | 3.597 | 0.409 | 0.992 | 0.046 | 0.427 | 1.074 |
| STUD 10 | 148659.4 | 325097.3 | 3.30299 | 148659.3 | 325097.5 | 3.59802 | 0.029 | -0.163 | -0.295 | 148659.469 | 325096.969 | 3.498 | 148659.286 | 325097.539 | 3.584 | 0.183 | -0.570 | -0.086 | 0.338 | 0.604 |
| STUD 20 | 148735.3 | 325091.1 | 3.62514 | 148735.5 | 325091.4 | 3.59685 | -0.122 | -0.352 | 0.028 | 148735.211 | 325090.352 | 3.617 | 148735.386 | 325091.497 | 3.606 | -0.175 | -1.145 | 0.011 | 0.374 | 1.159 |
| STUD 11 | 148660.3 | 325085.4 | 3.46674 | 148660.3 | 325085.6 | 3.58834 | 0.003 | -0.136 | -0.122 | 148660.311 | 325085.125 | 3.559 | 148660.224 | 325085.652 | 3.578 | 0.087 | -0.527 | -0.019 | 0.182 | 0.534 |
| STUD 1 | 148734.4 | 325103.5 | 3.61098 | 148734.6 | 325103.3 | 3.59685 | -0.182 | 0.226 | 0.014 | 148734.133 | 325103.892 | 3.611 | 148734.503 | 325103.180 | 3.604 | -0.371 | 0.712 | 0.007 | 0.291 | 0.803 |
| STUD 12 | 148664.5 | 325074.8 | 3.58910 | 148664.8 | 325074.5 | 3.58973 | -0.235 | 0.299 | -0.001 | 148664.004 | 325075.311 | 3.599 | 148664.773 | 325074.571 | 3.574 | -0.769 | 0.740 | 0.026 | 0.380 | 1.068 |
| STUD 2 | 148730 | 325113.9 | 3.77085 | 148730 | 325114.4 | 3.59457 | 0.017 | -0.561 | 0.176 | 148730.109 | 325112.796 | 3.670 | 148734.503 | 325103.180 | 3.604 | -4.394 | 9.616 | 0.067 | 0.588 | 10.572 |
| STUD 13 | 148672.4 | 325065.7 | 3.60374 | 148672.6 | 325065.4 | 3.58607 | -0.163 | 0.244 | 0.018 | 148672.280 | 325066.026 | 3.606 | 148672.475 | 325065.504 | 3.579 | -0.195 | 0.522 | 0.027 | 0.294 | 0.558 |
| STUD 3 | 148722 | 325124.1 | 3.74873 | 148721.9 | 325123.8 | 3.59854 | 0.141 | 0.322 | 0.150 | 148722.382 | 325124.575 | 3.665 | 148721.817 | 325123.818 | 3.612 | 0.565 | 0.757 | 0.053 | 0.382 | 0.946 |
| STUD 14 | 148682.7 | 325059.4 | 3.64853 | 148682.8 | 325059.2 | 3.58672 | -0.128 | 0.262 | 0.062 | 148682.613 | 325059.751 | 3.621 | 148682.692 | 325059.250 | 3.578 | -0.079 | 0.501 | 0.042 | 0.298 | 0.509 |
| STUD 4 | 148712 | 325129.8 | 3.63001 | 148712 | 325129.7 | 3.60084 | -0.005 | 0.049 | 0.029 | 148712.067 | 325129.806 | 3.621 | 148711.952 | 325129.769 | 3.619 | 0.115 | 0.037 | 0.002 | 0.057 | 0.121 |
| STUD 15 | 148694.1 | 325056.3 | 3.71912 | 148694.4 | 325056.3 | 3.59913 | -0.313 | -0.031 | 0.120 | 148693.718 | 325056.021 | 3.648 | 148694.299 | 325056.450 | 3.584 | -0.581 | -0.429 | 0.064 | 0.337 | 0.725 |
| STUD 5 | 148700.2 | 325132.5 | 3.55766 | 148700.4 | 325132.5 | 3.60325 | -0.199 | -0.039 | -0.046 | 148699.844 | 325132.366 | 3.593 | 148700.351 | 325132.566 | 3.602 | -0.507 | -0.200 | -0.009 | 0.208 | 0.546 |

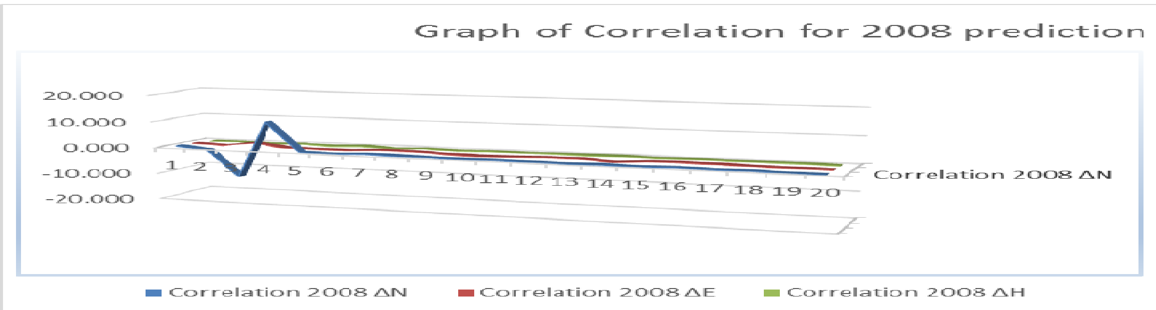


Figure 5: Graph of correlation for year 2008

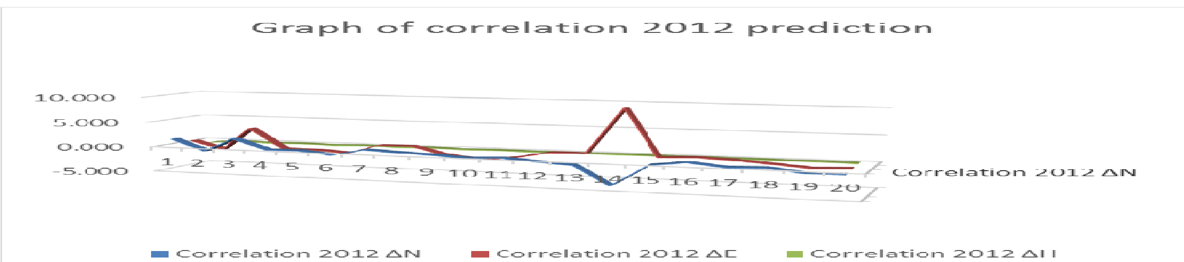


Figure 6: Graph of correlation for year 2012

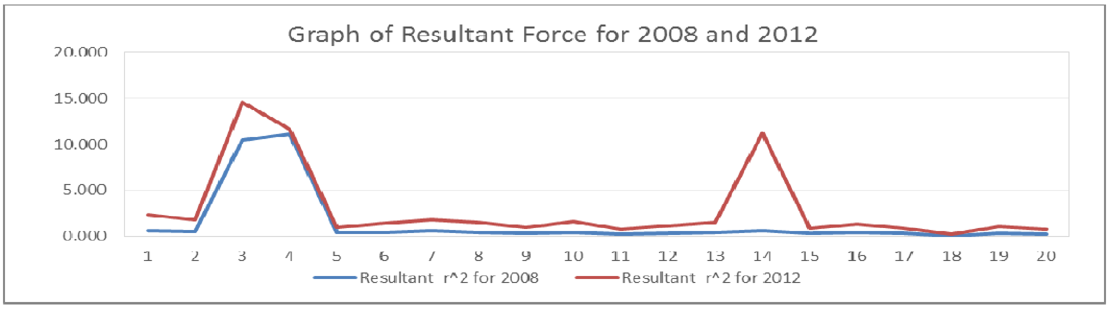


Figure 7: Graph of Resultant force for 2008 and 2012

## 7.0 Conclusion

In this study, a Kalman filtering technique based kinematic deformation analysis procedure has been applied on a data set collected in Forcados Tank Farm, Nigeria. In addition to this technique, the data has also been analyzed by static deformation analysis. Two different approaches produced identical results. However, the kinematic model has some clear advantages. For example, in kinematic model time dependent motion parameters of each point can be determined. Stepwise computation of motion parameters eases the control of the computations and the interpretation of the results. It is obvious that, for the computation of motion parameters or in other words for modelling the motion, more measurements are required. This is actually the main drawback of kinematic deformation model approach. In this study, in order to overcome this problem, Kalman filtering technique has been conducted for the computation of motion parameters. The main advantage of Kalman filtering technique is that it requires less measurement period. However, since the Kalman filtering technique employs prediction, the kinematic behaviours should not be extended unlimitedly by extrapolation. However, this study focused only on the geodetic deformation prediction process using measured value. It is clear that, through the combination of different data sets, a more realistic deformation was found. From the above, we have been able to prove that prediction of deformation value is possible using Kalman Filter. The graph of correlation reveals the accuracy of prediction when compared with the measured deformation value for 2004, 2008 and 2012 respectively.

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