QUALITY ASSURANCE CHARTS FOR PRECISE DETERMINATION OF CYLINDRICAL TANK DEFORMATION USING GROUND SURVEYING

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Abstract

The point position determination on a cylindrical tank wall is subject to some uncertainty due to angle of observation, distance from the tank, instrument precision and tank curvature. A formula is developed to represent the effect of these parameters on the uncertainty of the position of point. It has been converted to a group of charts that can be used to determine these parameters that assure the accuracy required in determining the point position.

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Introduction

Some deformation of 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 cause additional stresses not considered in the design on the shells forming the tank walls, (Berry et al, 2000). 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 (Chrzanewski et al, 2003). 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 surveying is a viable method that can be used to determine deformation of such tanks. The precision of the measured deformation depends on the accuracy of the surveying control system on the site and the precision of the instrument used.

In depots like that of oil industry, tanks are surrounded by many horizontal and vertical obstacles. Pipes in and out, pipe network that connect tanks, pumps, protection walls, fire control systems etc… are main obstacles that limit the spaces required for setting control surveying points. Therefore a procedure must be followed by the designer of the monitoring survey in order to plan the measurements that they fulfill the required accuracy and fit in such crowded sites by using the available equipment.

The main objective of this study is to develop guiding charts to relate three main parameters that affect the design of such measuring task. They are the accuracy needed for measuring deformation (tolerance), the tank diameter and the precision of the available surveying instrument. According to the relation of these three parameters, the maximum distance between the instrument and the tank as well as the maximum deviation horizontal angle from the tank centerline direction could be determined. It is necessary for the surveying engineer to know the proper locations for setting out the ground control points (or observation station) that determines the distortion with the required precision.

The monitoring procedure that will be considered in this research is the one that is described in detail by (Aguib, 2004). It depends mainly on marking the tank shells by equally spaced vertical lines. Along these vertical lines reflecting stickers are mounted at the middle of each ring shell to be the deformation observed points.

Methods of Deformation Measurement of Structures

The measuring techniques and instrumentation for structural deformation monitoring have traditionally been categorized according to the disciplines of professionals who use them. The first are the geodetic surveys and include the so called industrial geodesy. This technique includes conventional (terrestrial), photogrammetric, satellite, and some special techniques (interferometry, hydrostatic leveling, alignment, etc.). The second technique based on geotechnical/structural measurements of local deformations using lasers, tilt meters, strain meters, extensometers, joint-meters, plumb lines, micrometers, etc., (US Army Corps E, 2002).

Traditionally, geodetic surveys have been used mainly for determining the absolute displacements of selected points on the surface of the object with respect to some reference points that are assumed to be stable. The geodetic procedures allow for the long term monitoring of deformation (epochs of normally many years) and depends on the surveying design, skills of the observing persons and the accuracy of the instruments used. Geotechnical measurements have mainly been used for relative deformation measurements within the deformable object and its surroundings. The geotechnical technique can provide near real-time values for the deformations and requires one time set of instrumentation with quick checks from time to time to ensure correct operation. It is considered as short term measuring system.

Rotter et al (1996) have developed a technique to measure the surface profile. It depends mainly on special apparatus (measuring trolley) designed for this purpose. When this trolley pulled over a measured surface, continuously records the information on the geometric shapes of the surface. The recorded information is then used to calculate the profiles of the measured surface based on least-squares principles.

The method considered here is a conventional method that uses a total station for measuring slope distances, horizontal directions and zenith angles, from which coordinates are calculated. The observed points are marked on the deformable tank by reflecting stickers. The error in determining the point position due to the uncertainty of angle measurement by the instrument is referred here as the uncertainty of point position. The uncertainty of the sticker (or target) point position depends on two main sources; the precision of the measured angles (horizontal and vertical) and precision of the electromagnetic system, which is used for measuring distances to the instrument. In this investigation, only the effect of the precision of the horizontal direction measurements will be considered in determining point position uncertainty on the curved tank wall. In such cylindrical tanks the error due to the horizontal direction measurement is more effective than the vertical since it combines with the effect of tank curvature, while there is no curvature along the vertical line of the tank wall. It should be noted here that the effect of the vertical refraction on the line of sight is not considered in this investigation, since we are dealing with horizontal angles only. However, horizontal refraction, which is ignored here also, might have an effect on the line of sight if it passes close (and parallel) to the object or any other tank wall.

The deformation monitored in this situation is a horizontal movement of points in two dimensions only. Movement in the vertical (third) direction is mainly due to settlement and is measured along the lower ring (only) of the tank (no necessary to be measured at upper rings of the tank wall). Precise leveling procedure is the best to be used for settlement determination and requires different preparation in the site and on the tank lower ring for elevation determination of the monitoring points; this issue has been investigated by (Aguib and Bahr, 2000).

Parameters and Formulation

When using instrument (like total station) in determining the position of points, there will be uncertainty in the position of measured point on the tank wall. The uncertainty of measurement is defined as : a statement of the limits of the range within which the true value of a measurement is expected to lie at a given level of confidence, (United Kingdom Accreditation Service UKAS 2000). The term uncertainty is used also as “a measure of the possible error in the estimated value of the measurand as provided by the result of a measurement” (International Organization for Standardization, 1995). It is used here as alternate to the error that might result due to the uncertainty in angular measurements.

In the present case the uncertainty will depend on the instrument precision (θ) and the deviation angle from the control point – tank center direction to the measured point (β). The uncertainty distance along the tank wall is considered in our case as the tolerance permitted by tank designer in determining the point location on the curved tank wall and denoted here by (*u*). Figure (1) shows the parameters used in the case observations to a circular tank.

The following equation can express the relation between the different parameters affecting the uncertainty value. They are tank radius (*r*), precision of angle measured by the instrument (*θ*) and distance between the point of observations station and the tank center (*x* + *r*).

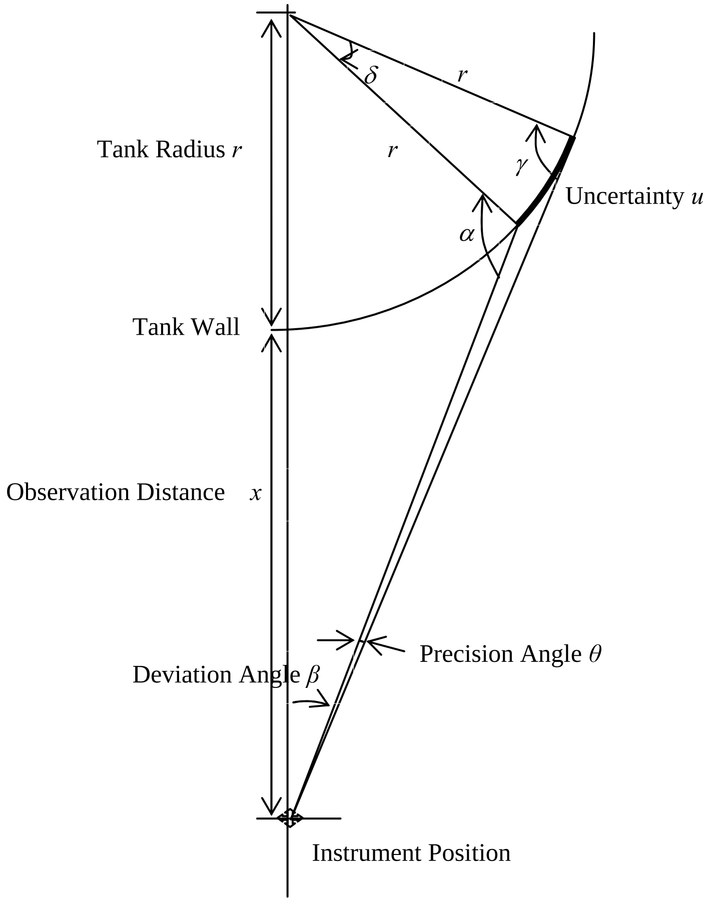

Figure (1) Formulation parameters for measurement uncertainty

For tank with radius *r*, the uncertainty value on the tank wall could be stated as $u = r\delta$, where *δ* is the central angle (in radians) corresponding to the uncertainty distance on the tank perimeter.

From Figure 1 the relations in Equations 1-3 are deduced:

$$\alpha = \gamma + \theta + \delta \quad (1)$$

$$\frac{\sin\gamma}{r+x} = \frac{\sin(\beta+\theta)}{r} \quad (2)$$

$$\frac{\sin\alpha}{r+x} = \frac{\sin\beta}{r} \tag{3}$$

The maximum deviation horizontal angle from the instrument point and the tank centre β could be calculated from Eq. (3) as:

$$\beta = \sin^{-1}\frac{r\sin\alpha}{r+x} \quad , \quad \text{where } \beta \text{ ranges between 0, and } \sin^{-1}(r/(r+x)) \tag{4}$$

From Eq. (2)

$$\gamma = \sin^{-1}\frac{r+x}{r}\sin(\beta+\theta) \tag{5}$$

and from equation (3)

$$\alpha = \sin^{-1}\frac{r+x}{r}\sin\beta \tag{6}$$

Then the uncertainty value u can be written as:

$$\begin{aligned} u &= r\delta = r(\alpha-\gamma-\theta) \\ &= r[\sin^{-1}\frac{r+x}{r}\sin\beta - \sin^{-1}\frac{r+x}{r}\sin(\beta+\theta) - \theta] \end{aligned} \tag{7}$$

The distance of the instrument from the tank x and its corresponding maximum deviation angle value *β* are calculated when the tolerance value *u*, radius of the tank r, and the value of instrument angular precision *θ* are determined. Using the above relations, charts could be developed by means of the Matlab software for the different values of tolerance u (1, 2 and 3 cm), tank radius *r* (3, 4, 5 and 10 m), instrument precision *θ* (1”, 2”, ……., up to 10”) to get maximum angle *β* and the corresponding instrument offset (*x)* for each condition.

The procedure followed is by calculating the tolerance *u* values for each incremental value of observation distance *x* and the corresponding deviation angle value *β* until reaching the defined tolerance value of *u*. This process is made for each tank radius *r* and each angular precision *θ*. Then charts are drawn between distance *x* (meters) and maximum deviation angle *β* (degrees) for each precision *θ* at each tank radius *r*.

Evaluation

Figures 2, 3, and 4 show the Charts that are calculated and plotted for tank radii of 3 m, 5 m and 10 m, using instrument with a least count in measuring angles ranging from 1” to 10”. The governing parameters for these Charts is the uncertainty (tolerance) allowed by design standard for locating observable points on the tank walls. Three values of the tolerances were considered; 1, 2, and 3 cm. Charts which were drawn by means of Matlab11 software programming showed that for 1 cm tolerance only instrument with accuracy up to 6 “ could be used and with maximum distances of about 320 m for all tank radii. It also showed that more precise instruments could be used from farther points from the tanks and with wider deviation angle.

Maximum distances in these charts are set to be 340, 420 and 500 m for 1, 2, and 3 cm tolerances respectively. The charts showed that smaller tank radii require closer observing distances than bigger ones for the same tolerances. This is , however, an expected outcome.

Additional charts could be developed for different tank radii and permissible errors. The charts show, as expected, smaller deviation angles β and the smaller observation distances x correspond to smaller tank radii if the tolerance remains the same. Also it shows that the more precise instrument (smaller θ) could allow for bigger deviation angle for the same observation distance.

With the aid of these types of charts surveying engineers can accurately plan the positions of observing stations on the site plan. That will assure the quality of the surveying work and allow the use of available surveying instrument with predictable outcomes. It is a positive point since it addresses the economy aspect of monitoring surveys. As mentioned before, such charts are important for selection of the proper location for survey control points on sites where there are obstacles. In such cases alternative positions could be chosen easily, while keeping the required measuring accuracy using angle measuring instrument with precisions ranging from 1” to 10”.

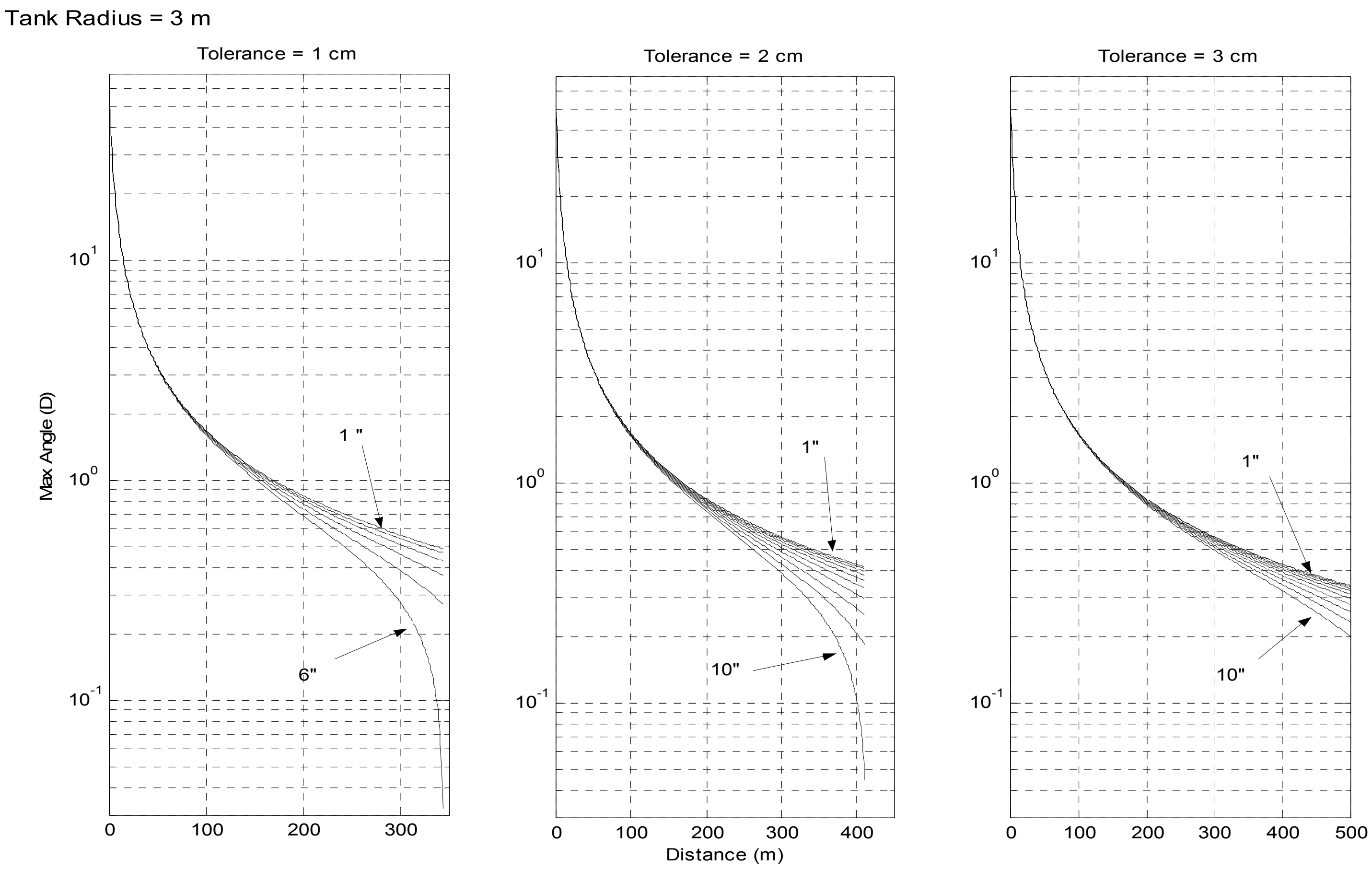

Figure (2) Charts for tank of radius 3 meters showing relations among maximum deviation angles (degree) and its corresponding distance (m) between the instrument and the tank wall for different instrument precisions (seconds).

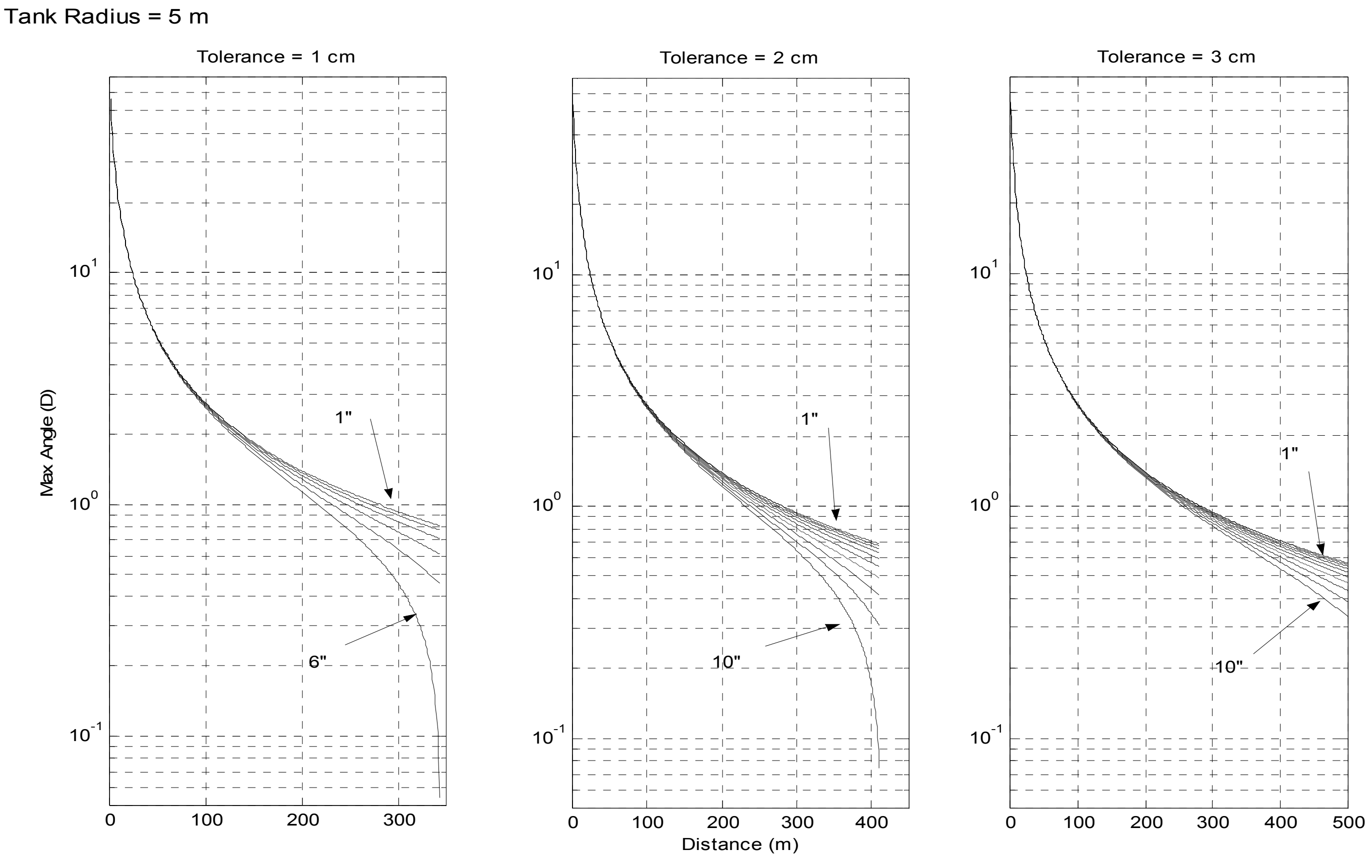

Figure (3) Charts for tank of radius 5 meters showing relations among maximum deviation angles (degree) and its corresponding distance (m) between the instrument and the tank wall for different instrument precisions (seconds)

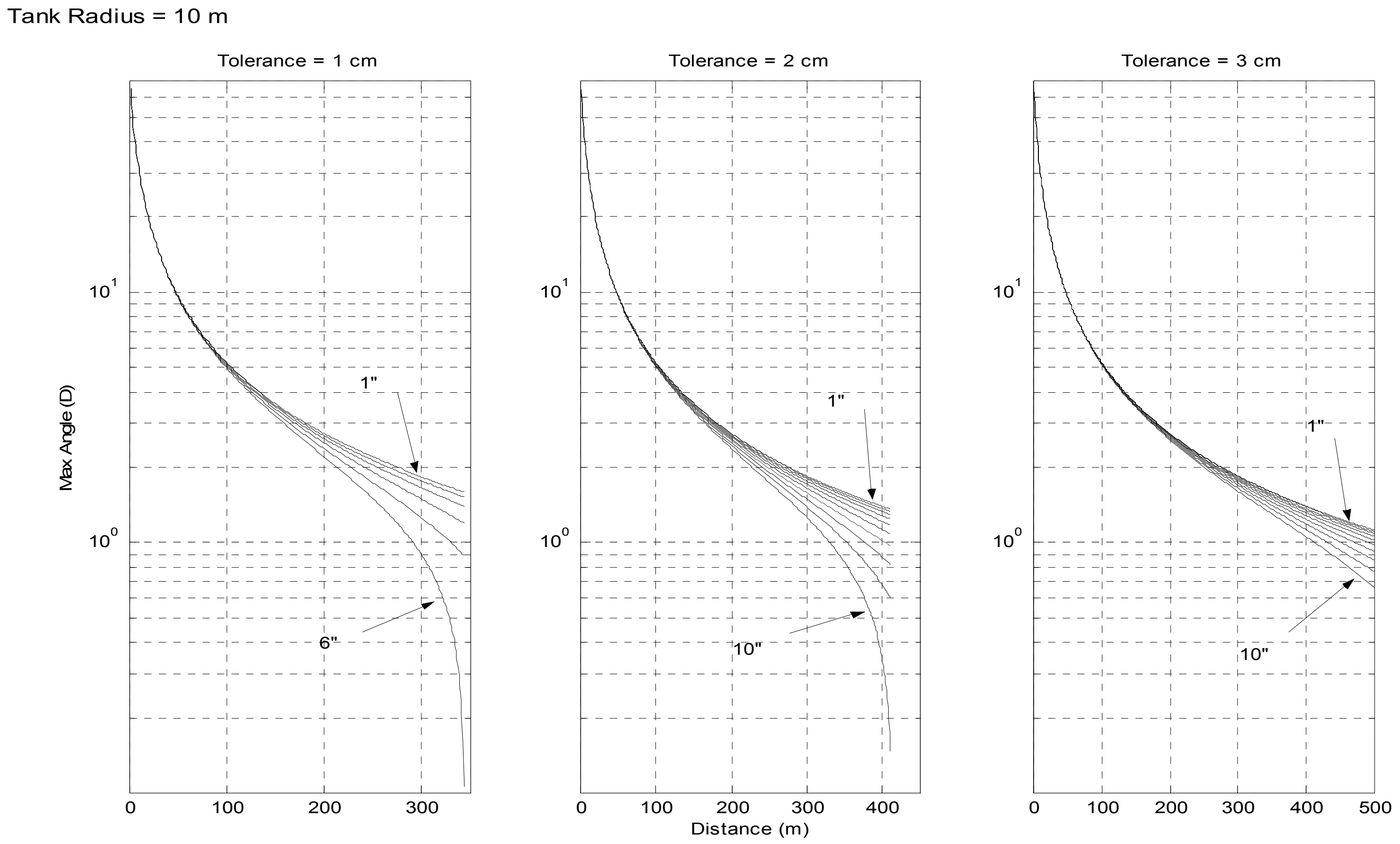

Figure (4) Charts for tank of radius 10 meters showing relations among maximum deviation angles (degree) and its corresponding distance (m) between the instrument and the tank wall for different instrument precisions (seconds)

Conclusions and Recommendations

Large tanks with thin cylindrical shells are subject to imperfection in their geometry due to fabrication quality and/or excess stresses due to loading and soil problems. The monitoring of such deformation measurement can be done by means of repetitive ground surveys over long period of time. The procedure consists on marking tank walls by means of reflecting tape marks observed by total station to locate their position changes within a local coordinate system. The precision of such measurements depends on instrument used and on the survey design. Guiding charts are developed in this research to assure the quality of such survey measurements for tanks in depots; where exist crowded piping systems and accessories restrict the design of monitoring networks and their geometry.

The charts correlate the tolerance accepted in point position with the maximum observing distance from the tank and the corresponding maximum deviation horizontal angle from the direction of the tank centre to observation point. The charts are plotted for different instrument precision in measuring horizontal directions (from1” to 10”) taking into consideration different tank radii (3, 5 and 10 m). The governing parameters for these charts are the uncertainty (tolerance) that is allowed by design standard for coordinating points on the tank walls. The charts are drawn to provide maximum distances and deviation angles that correspond to tolerances of 1, 2, and 3 cm. Charts are drawn by means of Matlab11 software programming and show that for 1 cm tolerance only instrument with angular precision up to 6” could be used and with maximum distances of about 320 m for the four used tanks radius. It also showed that more precise instrument could be used from farther points from the tanks and with wider deviation angle. Maximum distances are set to be 340 for 1 cm tolerance, 420 meters for 2 cm tolerance and 500 meters for 3 cm tolerance. Smaller tank radii require closer observing distances than bigger ones for the same tolerances.

In conclusion the type of charts developed in this paper proved to be important for assuring the quality of the surveying needed in cylindrical oil tanks in depot of oil industry and similar industries. Using the same formulation similar Charts could be drawn for tanks with different radii, tolerance, and equipment precision.

It is recommended that a similar study be carried out to discuss the uncertainty in point position due to precision of distance measuring system.

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