OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Evaluation and Accuracy Assessment of Static GPS Technique in Monitoring of Horizontal Structural Deformations

Prof. Dr. A.K. Abdel-Gawad[1], Dr. Y. M. Mogahed[2],
Dr. Kh. M. Abdel Mageed[3], Eng. A.M. El-Maghraby[4]

[1] *Civil Engineering Department, National Research Center, Egypt*
[2] *Public Works Department, Faculty of Engineering, Ain Shams University, Egypt*
[3] *Higher Technological Institute, Egypt*
[4] *Enppi, engineering for the petroleum and process industries*

Abstract: *It is well known that, deformation monitoring systems are considered, nowadays, to be the back bone factor for human safety as well as preserving the ultimate economy of his achievements. In this context, there has been always an increasing demand for precise deformation measurements in keeping up several engineering structures and historical monuments. Measuring and monitoring monumental deformation is the sequence of operations that allows the finding of movements of points or features in a specified coordinate system, during two different times for the same investigated feature. The time interval sometimes is the main factor in measuring horizontal deformation, especially in loading test of steel bridges. Hence, the present paper investigates the accuracy of the GPS in monitoring of horizontal deformation with respect to the time of observation. So, a practical simulation test was made to assess the accuracy of GPS with time in measuring horizontal deformation. The obtained results indicated that, the used methods and techniques presented in the current research paper have possessed a very good accuracy, reliability and applicability in monitoring horizontal deformations efficiently. The accuracy of measuring horizontal deformation of points on structure using relative static technique of GPS is from (0.1mm) to (1.8mm) for time interval from 30 minute to 5 minute and has R.M.S.E (0.3mm)*

Key words: *Deformation measurement – Horizontal Deformation – GPS - GPS accuracy – Static GPS Positioning.*

I. Introduction

It is well known that, deformation monitoring systems are considered, nowadays, to be the back bone factor for human safety as well as preserving the ultimate economy of his achievements. In this context, there has been always an increasing demand for precise deformation measurements in keeping up several industries, like structure buildings for instance, as well as several engineering structures and historical monuments. Such deformations constitute some problems from the structural point of view. Thus, it is necessary to measure and monitor such deformations before the repair stage; during the repair and after finishing the repair. This is essential to avoid any undesirable consequences that may happen and cause disaster risks of any part of the monument with time.

The deformation of any object can be defined as the variation of its position, size and shape with respect to its original state or its designed shape. The purpose of measuring deformations is not the calculation of the exact positions of the observed object but the variation of these positions with time. This is done to avoid failure of the structures (monuments). The methods used for monitoring deformations may be generally classified as surveying methods and non-surveying methods. The selection of the method of measurements depends upon the accuracy requirements. This, in turn, is determined by the purpose of the measurements and by the magnitude and direction of the expected deformations or movements **[1], [2], [3], [4], [5],** and **[6].**

Hence, many modern surveying techniques can be used in measuring and monitoring deformations **[7]** and **[8]**. On the other hand, the main problem is the suitability of measuring according to the site obstacles as well as the required accuracy. In terms of productivity and time saving, GPS could provide more than 75% time saving **[9]** and **[10]**. The fact that GPS does not require inter-visibility between stations has also made it more attractive to surveyors over the conventional methods.

Other advantages of the GPS system, as mentioned by **[11]**, are:

- GPS can easily cover larger areas than classical surveying methods, with millimeter level precision.
- The results between consecutive surveys are coherent **-** the procedures, data capture and computation are always the same, regardless of the operator and the particular GPS equipment.
- After a due training period, the equipment is easy to operate. The operator does not have to be an experienced surveyor.

Nonetheless, **[12]** listed additional advantages of the Global Positioning System versus the traditional surveying:

- GPS is an all-weather navigating system, except in thunderstorm.
- GPS is a day and night surveying tool.
- With GPS, human mistakes are eliminated.
- GPS serves many applications.
- Unlimited base line length.
- Un-necessity for visibility between points.
- GPS doesn't require huge man effort in measurements

Basically, the GPS observables are ranges which are deduced from measured time or phase differences based on a comparison between received signals and generated signals. Unlike the terrestrial distance measurements, GPS uses the so-called one-way concept, where, two clocks are used, namely one in the satellite, and the other in the receiver. Thus, the ranges are affected by satellite and receiver clocks errors and, consequently, they are denoted as pseudoranges **[13]**.

Mainly, there are two types of GPS observables, namely the code pseudoranges and carrier phase observables. In general, the pseudorange observations are used for coarse navigation, whereas the carrier phase observations are used in high-precision surveying applications. That is due to the fact that the accuracy of the carrier phase observations is much higher than the accuracy of code observations. Beside the two GPS observables, the GPS satellite transmits a navigation message. The navigation message is a data stream added to both L1 and L2 carriers as binary bi-phase modulation at a low rate of 50 Kbps. It consists of 25 frames of 1500 bits each, or 37500 bits in total. This means that, the transmition of the complete navigation message takes 750 seconds. The navigation message contains, along with other information, the coordinates of the GPS satellites as a function of time, the satellite health status, the satellite clock correction, the satellite almanac, and atmospheric data. Each satellite transmits its own navigation message with information on the other satellites, such as the approximate location and health status **[14]**.

There are different GPS relative positioning techniques. These techniques are static, stop and go, kinematic, and real time kinematic RTK. Static GPS technique, is an accurate and reliable technique, however, it is relatively slow in production. On the other hand, each one of other remaining techniques, is represented a technological solution to the problem of obtaining high productivity, such as measuring many baselines in a short period of time, or the ability to obtain results even while the receiver in motion, that is real time solution, however, with a relatively less accuracy than the static case **[15]**.

The biases that are affecting the GPS measurements fall into three categories which are: satellite biases, receiver biases, and signal propagation biases **[13]**. Satellite biases consist of biases in satellite ephemeris, satellite clock, and the effect of selective availability SA which is terminated in May 2000. Receiver biases usually consist of receiver clock bias, receiver noise and antenna phase center variation. The signal propagation biases appear due to tropospheric refraction, ionospheric refraction, and multipath. Beside the effect of these biases, the accuracy of the computed GPS position is also affected by the geometric locations of the GPS satellites as seen by the receiver. Generally, the more spread out the satellites are in the sky, the better the obtained accuracy, which is denoted as dilution of precision.

So, the main objective of the current research paper is to investigate the feasibility and applicability as well as accuracy assessment of the GPS in measuring horizontal deformation of structures. To achieve this objective, a simulation test was made to assess the accuracy of GPS in monitoring horizontal deformations of structures. Hence, the purpose of this experiment is to determine the horizontal deformation of the bolts positions relatively with each other by GPS technique compared with their position measured relatively by the scaled vernier.

II. Methodology of Investigation

To assess the accuracy of the GPS in monitoring horizontal deformation, a simulation was made following the next steps:

1- Fixing of bolts at the roof of faculty of engineering, Ain Shams University.
2- Measuring the horizontal distances between bolts with scaled vernier with an accuracy of 0.05 mm.
3- Measuring the horizontal distances between bolts using three GPS receiver. Two receivers are fixed and the third one is moving through the fixed bolts, using the slight movement of the legs.
4- Comparative study was done between the scale vernier measurements and the GPS measurements. The first solution uses one GPS fixed point. The second solution uses two GPS fixed points.

III. The Used Instruments

All instruments used in this test are tested and adjusted before using it. Such instruments are:
1-a vernier scale which model is (SOMET INOX) shown in figure (1) (divided scale as shown).

Figure (1) shows the distances between the bolts as well as the vernier scale.

2-Three GPS receivers (A,B&C)which are of model Trimble R3**[16].** Figure (2) shows the GPS Receiver.

Figure (2) shows the GPS Receiver over the simulated bolts

specifications and measurements of the GPS receivers are:
- 12 Channels C/A Code, WAAS/EGNOS
- Trimble Maxwell GPS technology for robust satellite tracking
- Trimble EVEREST™ multipath reduction technology
- Three tripod legs are available one for each receiver.

3-Rechargeable battery with electric cable to charge the GPS receivers in case of their battery is low.
4-A number of 6 bolts, 4 of them were used for the target points and 2 for static receivers.
5-A hammer used for fixing the bolts and markers for marking them.

IV. Description of the sight and fixing of control and monitored points

This experiment has been carried out at the faculty of engineering, Ain Shams University at The public works department building. The test was made on the roof of the building, this test was made to measure the horizontal displacement of the positioning of the bolts relative to each other and comparing these relative positioning using GPS with the positioning of them using vernier scale.

A net of 4 bolts (target points) are fixed on the roof of the building, and they were aligned on the same edge of the slab by distance 1 cm apart exactly between each bolt of them (with accuracy of 1/20 mm) using the (Vernier Marcasomethecho De AceroInoxiadble equipment) and the distance is measured 1 cm apart accurate between them and marked on every bolt to ensure right and perpendicular verticality on them by the tripod of the GPS. Figure (1) shows the position between the bolts where the distances were measured.

V. Observation procedure

In this test, the observations of the horizontal distances between the bolts which initially taken by the scale are then taken by GPS receiver. The first two receivers A&B where settled as static receivers and had a job opened in each one , receiver A was opened at first which was far 300 meters approximately from C, then B had job opened next ,which was away 50 meters approximately from C, then C was opened the last one.

The first receiver (A) was fixed on tripod and was horizontally adjusted and verticality adjusted by the screws of the tripod and using the slight movement of the legs until the bubble was at the middle exactly, and the antenna was placed on the tripod, then the height of the instrument was measured and entered until top of notch height, after that the GPS receiver was opened and had a new job named by that date and was created by the fast static technique job and occupied point named S1 and then the receiver began to search for a sufficient number of satellites and began to count working time.

The same procedures were done for the receiver (B) which was fixed on point named S2.

The same procedures were done for the receiver (C) which was fixed on bolts which are the observation target; each one of them had a session of half hour then switched to the other bolt. Which means that B1 had a job opened with a session half hour then after that switching to bolt B2 by movement of the tripod with the antenna by using the screw bolts and taking on B2 another session with half hour and the same switching to B3 with half hour then finally to B4 with half hour, all of that and the two static GPS receivers have the constant observation time without stop in order to have an overlap time between the receivers to have a process solution in the program after that in office work.

The precautions taken in consideration with the four sessions were necessary as taking care that the battery of the three GPS receivers wasn't consumed totally in order to have the three GPS receivers observing coordinates and working properly, also from the precautions that the number of satellites during the whole observation time for each receiver wasn't less than 4 in order to get coordinates for each point, also being sure that the three tripods are fixed well on the roof to keep verticality and horizontality of the antenna was considered during the experiment.

VI. Computations, Results and Analysis of Results

The idea here is to compute the difference in results between the GPS receiver and that of the scale to compare the accuracy and the applicability to use in deformation measuring projects.

6-1GPS obtained results and determining its accuracy with itself

To investigate the accuracy of GPS in monitoring the horizontal deformation according to every point with itself with different time intervals, the results of positioning of every bolt is computed using GPS results under conditions of cut off angle 15^o and reference receiver S1 only, the results of positioning of each bolt is compared in factor of different time intervals.

To investigate the GPS point positioning against itself, the difference of GPS results obtained for positioning of points B1, B2, B3 and B4 from time interval (5mins) to (30mins) were computed. Figure (3) shows the difference of GPS results obtained for positioning of point B1 from time interval (5mins) to (30mins) and it shows that error of positioning is from (0.2 to 1.7mm) where 0.2 mm accuracy is for the difference between the time intervals at 30 & 25 while the 1.7 mm error occurs at the difference between the time intervals at 10&5 minutes.

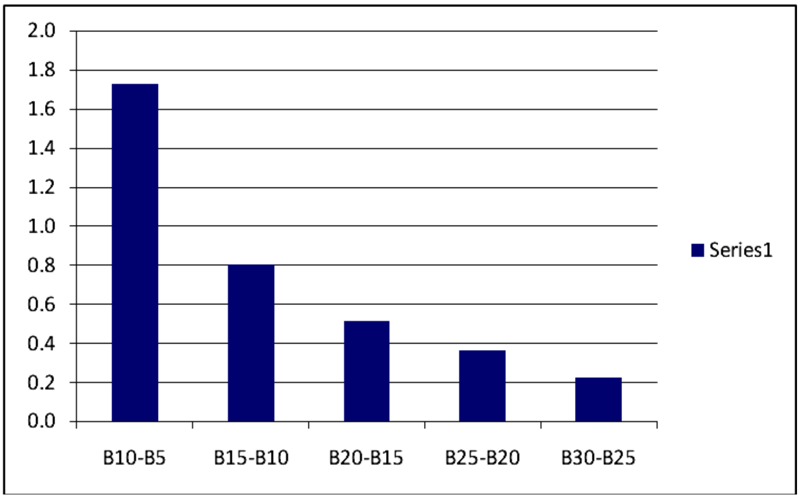

Figure (3) difference of horizontal positioning of B1from a time interval with the next referenced to control point S1 only in mm

6-2 GPS obtained results compared with that of vernier scale referenced to receiver A only

To investigate the accuracy of GPS in monitoring the horizontal deformation, the relative positions (distances) between the lined bolts are computed using GPS results and the measured distances using vernier scale each time interval which is 5 minutes under conditions of cut off angle 15^{o} and referenced to receiver S1 only. For assessing the GPS results for each time interval, the RMS of error was computed for all points shown in table (1).

Table 1: the RMS of horizontal displacement for all points at each time interval in mm

Diff.	RMS (5 Min)	RMS (10 Min)	RMS (15 Min)	RMS (20 Min)	RMS (25 Min)	RMS (30 Min)
b1-b2	0.40	-0.99	0.70	-0.30	-0.60	0.10
b2-b3	1.09	-0.08	0.40	-0.10	0.60	-0.10
b3-b4	1.81	1.22	1.10	-0.10	-0.50	-0.50
Tot.	2.15	1.58	1.36	0.35	0.98	0.51

Figure (4) shows the RMS of all points during the GPS time intervals.

The figure shows that the accuracy is increasing with the increase of time interval from 2mm at time interval of 5 minutes to 0.5 mm at time interval of 30 minutes and the RMS of time interval 20 minutes here is an outlier result where it was possible that the GDOP of the satellites was the best at that time or there was less GPS observation errors at that time interval.

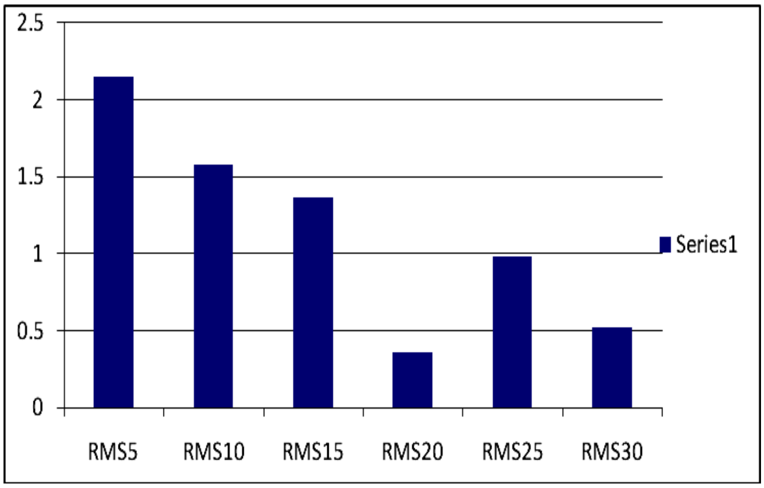

Figure (4) shows the RMS of all points during the GPS time interval in mm

6-3 GPS obtained results compared with that of VERNIER scale referenced to A&B

To investigate the accuracy of GPS in monitoring the horizontal deformation, the relative positions (distances) between the lined bolts are computed using GPS results and the measured distances using vernier scale each time interval which is 5 mins under conditions of cut off angle 15^{o} and referenced to receivers A&B and the software program solved the loop closure error adjustment. For assessing the GPS results for each time interval, the RMS of error was computed for all points referenced to receiver a and b shown in table (2)

Table 2: the RMS of horizontal displacement for all points at each time interval in mm

Diff.	RMS (5 Min)	RMS (10 Min)	RMS (15 Min)	RMS (20 Min)	RMS (25 Min)	RMS (30 Min)
b1-b2	0.24	-1.00	-0.70	-0.20	-0.60	0.10
b2-b3	1.20	-0.10	-0.40	-0.10	0.60	-0.10
b3-b4	1.68	1.20	0.01	-0.10	0.50	0.50
Tot.	2.07	1.56	0.80	0.24	0.98	0.52

Figure (5) shows the RMS of all points during the GPS time intervals.

The figure shows that the accuracy is increasing with the increase of time interval from 2mm at time interval of 5 minutes to 0.5 mm at time interval of 30 minutes and the RMS of time interval 20 minutes here is an outlier result where it was possible that the GDOP of the satellites was the best at that time or there was less GPS observation errors at that time interval.

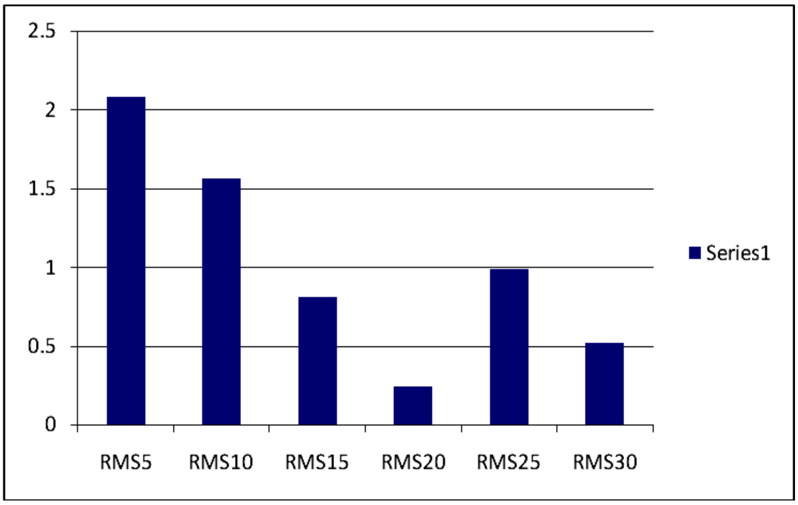

Figure (5) shows the RMS of all points during the GPS time interval referenced to receiver A &B in mm

VII. Conclusions

One of the main problems, facing the workers in structural or monuments repair, is the measuring and monitoring of deformations before, during, and after repair. Some of this important task has been solved in the present paper, through the evaluations of GPS accuracy in monitoring horizontal deformation. Based on the results of our practical investigation contained here, the following important conclusions can be enumerated:

1- The accuracy of measuring the horizontal movement using relative static technique resulted from GPS compared every point with itself is from about (0.2 to 2.7mm) and accuracy increases with the increase of the time interval of the observation.

2- The accuracy of measuring horizontal deformation of points on structure using relative static technique of GPS is from (0.1mm) to (1.8mm) and the best accuracy is for the 30 minutes time interval which reveals that moreover the time interval increase in the GPS, the accuracy increases.

3- The root mean square error decreases as the time interval increases as the 30 minutes gave the best accuracy while the 5 minutes gave the least accuracy

4- No need to use two static receivers in measuring and monitoring of horizontal structural deformations as the result of accuracy increase only by ratio 10% in the RMS of the points, where the cost of the project and saving the cost of an additional receiver to use two static receiver is more valuable than 10% increase in accuracy.

5- The applications of the horizontal deformation measurement and monitoring by GPS method can be used in some old monuments and high rise buildings or concrete bridges deformations and monitoring with accuracy about 3 millimeters.

REFERENCES

[1] El-Maghraby, M.F. and A.K. Abdel-Gawad, 2004, "Evaluation of Non-Photogrammetric Precise Surveying Techniques in Monitoring of Historical Monumental Deformations", Scientific Bulletin of the Faculty of Engineering, Ain Shams University, Vol.39, No.2, June 2004, 327-347.

[2] Abdel-Gawad, A. K., 1994,"The Applications of Highly Precise Surveying Techniques in Measuring Deformations of Structures", M.Sc. Thesis, Faculty of Engineering, Ain Shams University.

[3] Awad,M.I.1988, "Study of Geodetic and Other Techniques for Determination of Deformation of Tall Buildings in Egypt", M.Sc. thesis, Ain Shams University, Cairo.

[4] El-Tokhey, M. E., M. M. Awad, and A. K. Abdel-Gawad, 2001, "Theoretical Analysis and Experimental Field Test for using Total Stations in Measuring Deflections of Steel Bridges" The Scientic Bulletin of Civil Engineering, Al-Azhar University, Vol. No., July, 2001.

[5] Tesky, W.F. and L. Gruendig, 1985, "Modern Methodology in Precise Engineering and Deformation Surveys", PEDS Workshop, Division of Surveying Engineering, University of Calgary, Calgary, Canada.

[6] Stuart G., D. Lichti, M. Stewart and J. Franke, 2003, "Structural Deformation Measurement Usingterrestrial Laser Scanners", Proceedings of 11th FIG Symposium on Deformation Measurements, Santorini, Greece.

[7] El-Maghraby, A. M., 2013," Assessment of new surveying techniques in measuring and monitoring of structural deformations", M.Sc. Thesis, Faculty of Engineering, Ain Shams University.

[8] El-Tokhey, M. E., A.K. Abdel-Gawad, Y.M. Mogahed and A.M. El-Maghraby, 2013, "Accuracy Assessment of Laser Scanner in Measuring andMonitoring Deformations of Structures" World Applied Sciences Journal 26 (2): 144-151, 2013

[9] El-Rabbany, A., 2002, "Introduction to GPS: The Global Positioning System", Artech House Mobile Communications Series, Boston, London.

[10] Berg, R.E., 1996, "Evaluation of Real-Time Kinematic GPS Versus Total Stations for Highway Engineering Surveys", 8^{th} Intl. Conf. Geomatics: Geomatics in the Era of RADARSAT, Ottawa, Canada, May 24.30, 1996.

[11] Gili, J.A.; Corominas, J. and Rius, J., 2000, "Using Global Positioning System techniques in landslide monitoring", **Engineering Geology**, 55(3): 167-192.

[12] Blair, B.R., 1989, "Practical Applications of Global Positioning System", Journal of Surveying, Vol. 115, No. 2, May 1989.

[13] Abdel Mageed Kh, 2006, "Towards improving the accuracy of GPS single point positioning", Ph.D Thesis, Faculty of Engineering, Department of Public Works, Ain Shams University, Cairo, Egypt.

[14] Hofmann-Wellenhof B., H. Lichtenegger and J. Collins, 2001, "Global Positioning System, Theory and Practice", 5th Revised Edition, Springer-Verlag, New York

[15] Leick A., 1995, "GPS Satellite Surveying", A Willey Inter-Science Publications, John Willey & Sons, New York

[16] Trimble Company, 2010, "Trimble GPS Receiver R3 datasheet, www.trimble.com.