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Accuracy Assessmentof StaticGPS Techniquein Monitoringof Vertical Structural Deformations

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Abstract—Nowadays, deformation monitoring systems are very important task taking the human into consideration. In this context, there has been always an increasing demand for precise deformation measurements techniques. 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 vertical deformation, especially in loading test of steel bridges. Hence, the present paper investigates the accuracy of the GPS in monitoring of vertical deformation with respect to the time of observation. In this context, a practical simulation test was made to assess the accuracy of GPS with time in measuring vertical 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 vertical deformations efficiently. The accuracy of measuring vertical deformation of points on structure using relative static technique of GPS is from (0.2mm) to (20mm) and the best accuracy is for the 20 minutes time interval which reveals that moreover the time interval increase in the GPS, the accuracy increases.

Index Terms—Deformation measurement – Vertical Deformation – GPS – GPS vertical accuracy – Static GPS Positioning.

1 Introduction

Many huge structures and buildings have been constructed in Egypt during the recent years and are considered very sensitive and valuable structures. Any distortion, movement, or deformation in any element of the structure greater than the allowable values may cause a dangerous damage to the structure. Therefore these structural deformations must be measured and monitored during and after construction by using the most precise available techniques for the sake of human safety as well as economic considerations.

The insurance of the safety of such huge engineering constructions against any human or non-human hazards caused by any shortcoming in detecting and remedy of any expected deformations or damages has been the basic motivation behind under taking the present investigation.

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). Deformations can be classified from different points of view. Deformations may occur in horizontal or vertical directions as well as in space. Deformations may be treated as permanent or temporary deformations. Deformation measurements can be treated as relative or absolute. See figure (1).

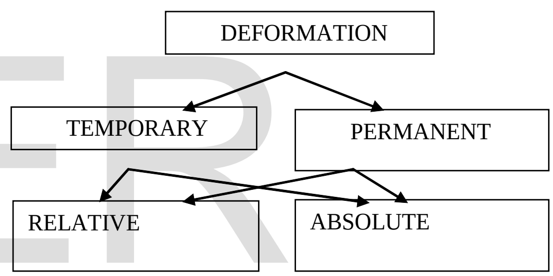

Fig. 1.Types of deformations

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],[5], [8], and [9]. Hence, the main objective of the current research is to study the practical feasibility, applicability, and accuracy of using GPS in measuring vertical deformation.

2 Basic Items of Deformation Monitoring Process

Deformation monitoring, whatever the structure involved is consists of four stages: Specifications, Design, Implementation and Analysis [12].
The specifications of the requirements of the monitoring scheme might seem straight forward for example, when a given magnitude of movement is required to be detected. However, the problem is more

involved than it might appear. In such a case the following four items must be carefully considered.

i. The confidence level of the movement to be detected.
ii. The required accuracy of monitored points as a whole or in part.
iii. The importance of the direction of the movement.
iv. Type of required movement either absolute or relative.

After defining the above items, the design stage of the monitoring procedure can be commenced. For instance, a deformation monitoring network must be designed to meet specific criteria, before any observations are actually made. After the design stage of such network, the instruments to be used can be selected and calibrated to observe the network with the required accuracy.

3 GPS Relative Positioning Technique

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. 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. The accuracy of code ranges is at the meter level, whereas the accuracy of the carrier phase is in the millimeter range [11]. The accuracy of the code ranges can be improved, however, by smoothing techniques. Also, the code ranges unambiguous, unlike the carrier phase [3].
The selection of the observation technique in a GPS survey depends upon the particular requirements of the project, and the desired accuracy especially plays a dominant role. This makes code ranges immune from cycle slip. The GPS observation techniques include: point positioning; differential positioning DGPS; and relative positioning. Also, relative positioning includes: static, rapid static, stop and go, kinematic, real time kinematic RTK. GPS point positioning employs one GPS receiver, while DGPS and relative GPS positioning employ two or more GPS receivers, simultaneously tracking the same satellites. Surveying works with GPS have conventionally been carried out in the relative and differential positioning techniques. This is mainly due to the higher positioning accuracy obtained from the relative and differential techniques, compared to that of the GPS point positioning [4].
GPS relative positioning, figure (2), also called differential positioning, employs two GPS receivers simultaneously tracking the same satellites to determine their relative coordinates [7]. Relative positioning is used to estimate relative coordinates of an unknown station with respect to a known station coordinates. This technique can either use the GPS code or for more precise results make use of phase observables [10]. The former provides the highest possible accuracy. GPS relative positioning can be made in either real-time or post mission modes. GPS relative positioning is used for high-accuracy applications such as surveying and mapping, Geographic Information System (GIS), and precise navigation. Of the two receivers, one is selected as a reference, or base, which remains stationary at a site with precisely known coordinates. The other receiver, known as the rover or remote receiver, has its coordinates unknown [7]. Because many errors will affect the absolute position of two or more GPS users to almost the same extent, most of these errors are cancelled when differential positioning is carried out. This is the standard mode for GPS surveying, which essentially measures the baseline components between simultaneously observing receivers.

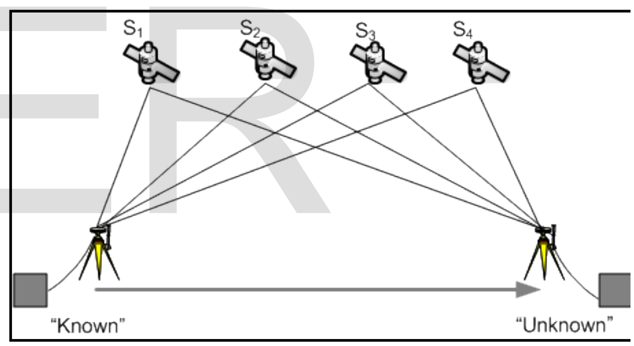

Fig.2.Relative Positioning Technique

4 Description Of The Field Test

The purpose of this experiment is to determine the vertical deformation of movement of the GPS antenna by the screw bolts of tripod which was measured exactly by precise level and comparing the results by the GPS static technique. The test was made on the roof of the building of the public works department, Faculty of Engineering, Ain Shams University [6].

- Fixation of the target points and control points

Three bolts were fixed, one as a target point and two as control points. Two static GPS receivers of Trimble R3 [13] were fixed on the roof of the buildings away from the target point and a rover GPS receiver of the same type was fixed on the target point. The two static GPS receivers A and B were fixed at first and had a job opened to ensure having an overlap time sufficient to

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solve the processing lines later on the program when processing the data.

In addition, three tripod legs for each 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 away approximately from C, then C was opened the last one. An optical precise level model Wild-N3 with a precise staff was used to get the precise levels of the GPS antenna (figure 3).

Fig. 3.The optical precise level settled in front of the GPS receiver about 5 meters away in order to have the staff readings above the antenna exactly

- Observation procedure

The observations of the vertical displacements of the GPS antenna was measured by the precise level by standing the precise staff on the GPS antenna then taking the reading on it right and left scale and checking the staff constant, after that opening the session for 20 minutes in the GPS receiver, then the second session we move the antenna vertically by a known displacement either upwards or downwards and measure it precisely by the precise level and staff and checking also the staff constant and having another session opened also.

These sessions which are (S3,BB,BB2, and BB3) were done 4 times with four intervals of time each interval is 20 minutes. The GPS antenna was moved upward and downwards vertically by the means of the bolts screw of the tripod where the screw bolts were opened and then moving the legs of the tripod if needed and rechecking again the horizontality and verticality of the antenna then taking the reading on the staff which is placed over the antenna then finally opening a session 20 minutes for the GPS antenna taking the observation.

5 Actual Deformation computation, results and analysis of results

The idea here is to compute the vertical deformation of the GPS antenna height by the GPS receiver and comparing its results referenced to the readings of the method of the precise level and staff, so we can know the accuracy of GPS techniques in measuring z deformation and its applicability in measuring these deformations in various engineering projects. Accordingly, one can compare the difference between two readings of the precise staff for two sessions with the difference between these two readings of the GPS receiver.

5.1. Analysis of GPS obtained results and determining its accuracy with itself

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

Figure (4) shows the difference of GPS results obtained for positioning of point S3 from time interval (5mins) to (20mins) and it shows that error of vertical positioning is from (1 to 3.5mm) where 1 mm accuracy is for the difference between the time intervals at 20&15 while the 3.5 mm error occurs at the difference between the time intervals at 15&10mins.

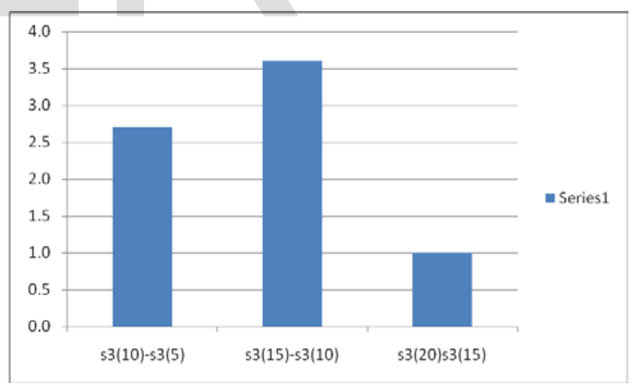


Fig. 4.Difference of vertical positioning of S3 from a time interval with the next referenced to control point S1 only

Figure (5) shows the difference of GPS results obtained for positioning of point BB from time interval (5mins) to (20mins) and it shows that error of vertical positioning is from (0.5 to 10.2mm) where 0.5 mm accuracy is for the difference between the time intervals at 10&5 while the 10.2 mm error occurs at the difference between the time intervals at 20&15 minutes.

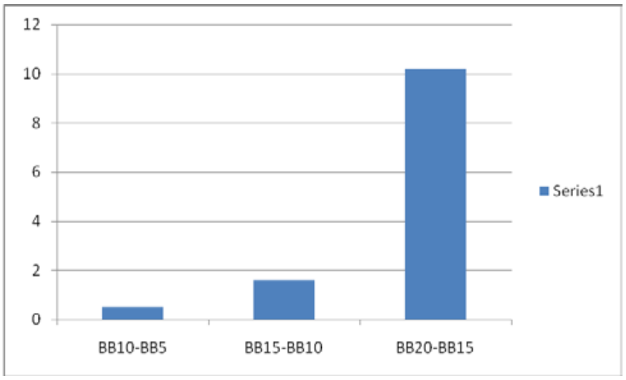


Fig. 5.Difference of vertical positioning of BB from a time interval with the next referenced to control point S1only

Figure (6) shows the difference of GPS results obtained for vertical positioning of point BB2from time interval (5mins) to (20mins) and it shows that error of positioning is from (0.1 to 1.5mm) where 0.1 mm accuracy is for the difference between the time intervals at 10&5 while the 1.5 mm error occurs at the difference between the time intervals at 15&10mins.

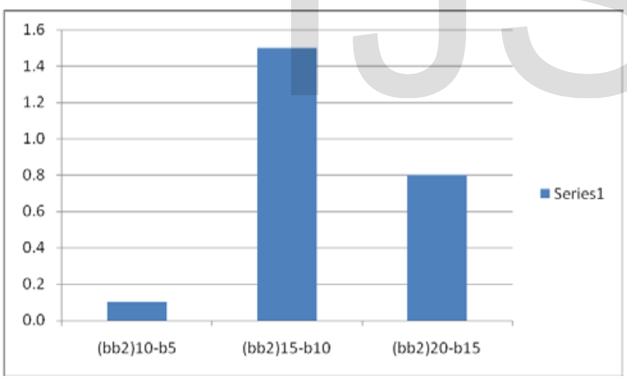


Fig. 6.Difference of vertical positioning of BB2 from a time interval with the next referenced to control pointS1 only

Figure (7) shows the difference of GPS results obtained for vertical positioning of point BB3from time interval (5mins) to (20mins) and it shows that error of positioning is from (0.35 to 3.2mm) where 0.35 mm accuracy is for the difference between the time intervals at 10&5 while the 3.2 mm error occurs at the difference between the time intervals at 20&15mins.

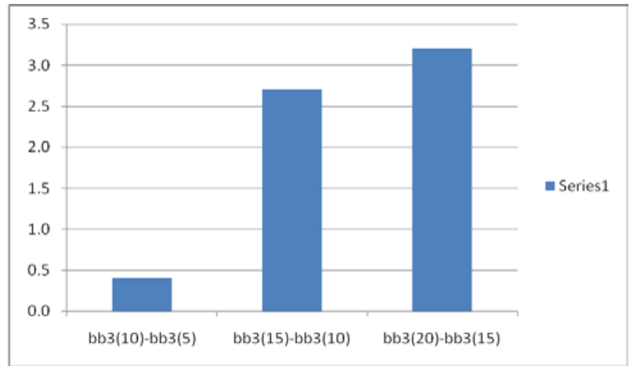


Fig. 7.Difference of vertical positioning of BB3 from a time interval with the next referenced to control point S1 only

5.2. Analysis of GPS obtained results compared with that of precise leveling to receiver A only

To investigate the accuracy of GPS in monitoring the vertical deformation, the relative positions (difference in level) between the GPS results and the precise leveling results are computed.

Figure (8) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 5 minutes. The results shows that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 10 & 20 mm

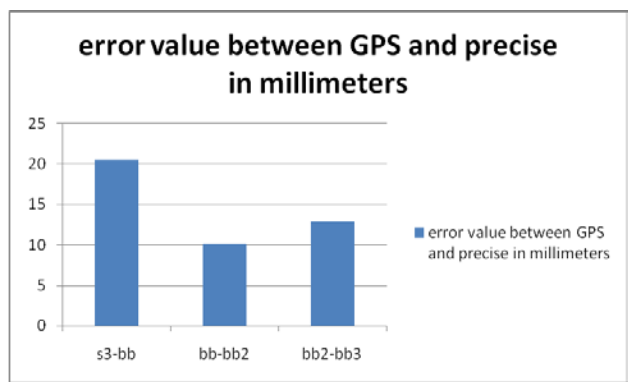


Fig. 8.Difference in levels between the GPS results and the precise leveling results after a GPS time interval of 5 minutes referenced to S1 only

Figure (9) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 10 minutes. The results shows that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 0.2 & 12.5 mm

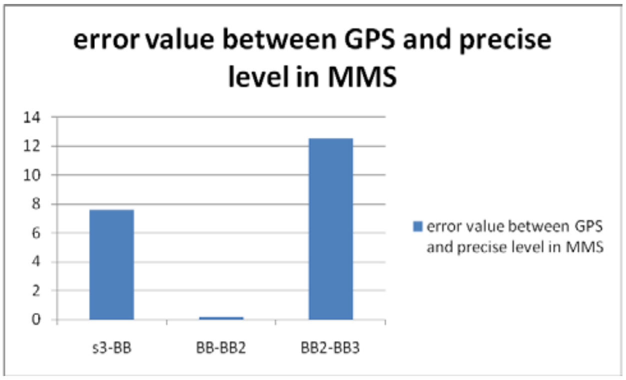


Fig. 9.Difference in levels between the GPS results and the precise leveling results after a GPS time interval of 10 minutes referenced to S1 only

Figure (10) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 15 minutes. The results shows that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 2.2&11 mm

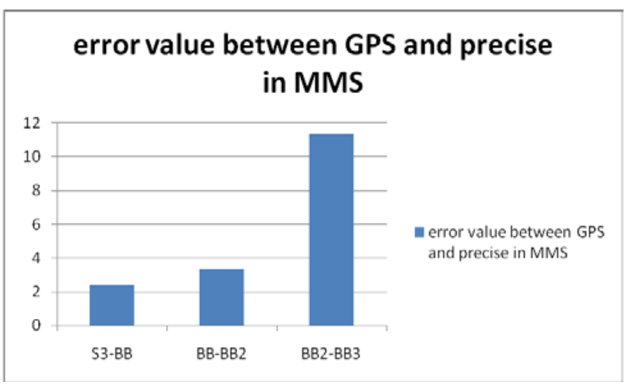
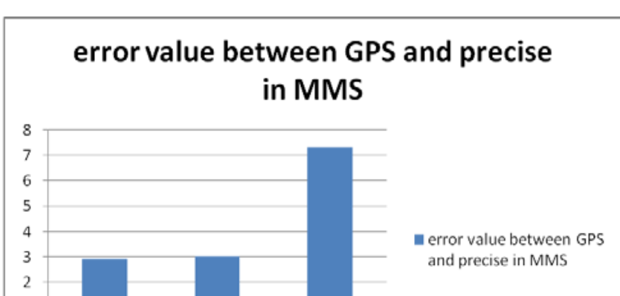


Fig. 10.Difference in levels between the GPS results and the precise leveling results after a GPS time interval of 15 minutes referenced to S1 only

Figure (11) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 20 minutes. The results shows that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 3 & 7 mm



For assessing the GPS results for each time interval, the RMS of error was computed for all points referenced to receiver A (point S1) as shown in table (1) which is computed by the formula

$$\sqrt{error(s3-bb)^2 + error(bb2-bb)^2 + error(bb3-bb2)^2}$$

Table 1
RMS of vertical displacement for all points at each time interval in mm

Time interval	5mins	10mins	15mins	20mins
Error in (S3-BB)	20.5	7.6	2.4	2.9
Error in (bb-bb2)	10.1	0.2	3.3	-3
Error in (bb2-bb3)	12.8	12.5	11.3	7.3
Root mean square error	26.19	14.63	12.01	8.40

Figure (12) shows the RMS of all points during the GPS time intervals referenced to s1 only. The figure shows that the accuracy is increasing with the increase of time interval from 26mm at time interval of 5 minutes to 8 mm at time interval of 20 minutes.

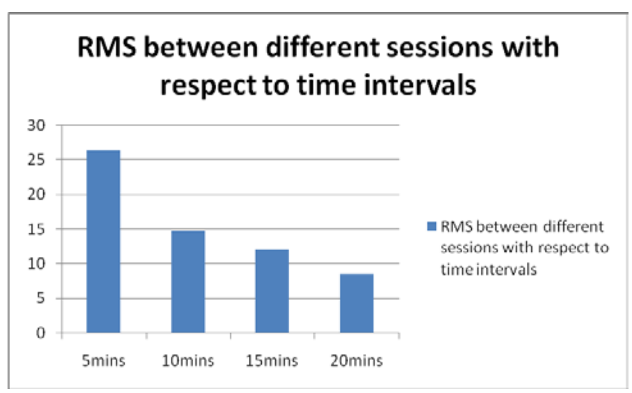


Fig. 12.RMS of all points during the GPS time interval referenced to receiver A

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5.3. Analysis of GPS obtained results compared with that of precise level referenced to receivers A&B

To investigate the accuracy of GPS in monitoring the vertical deformation, the relative positions (difference in level) between the GPS results and the precise leveling results are computed with time interval which is 5 minutes under conditions of cut off angle 15° and referenced to receivers A&B and the software program solved the loop closure error adjustment.

Figure (13) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 5 minutes. The results shows that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 0.6&10.9 mm

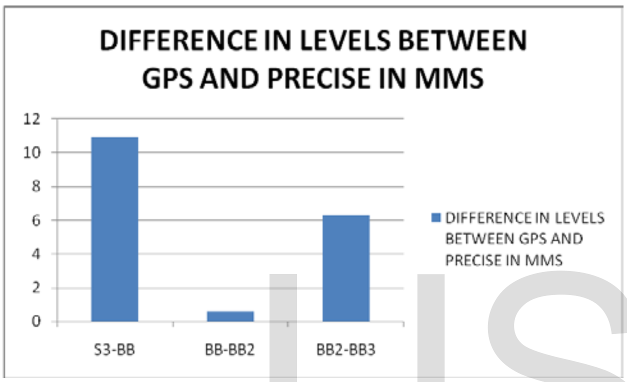

Fig. 13.Difference in vertical distance between the GPS results and the precise level after a GPS time interval of 5 minutes referenced to S1&S2

Figure (14) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 10 minutes. The results show that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 0.2 & 7.7 mm.

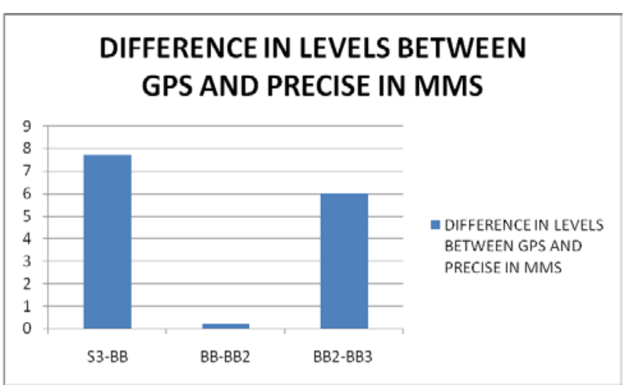

Fig. 14.Difference in vertical distance between the GPS results and the precise level after a GPS time interval of 10 minutes referenced to S1&S2

Figure (15) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 15 minutes. The results show that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 0.6 & 6.6 mm.

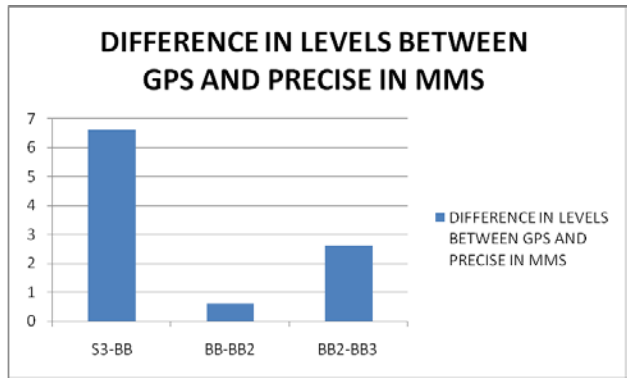

Fig. 15.Difference in vertical distance between the GPS results and the precise level after a GPS time interval of 15 minutes referenced to S1&S2

Figure (16) shows the difference in levels between the GPS results and the precise leveling results after a GPS time interval of 20 minutes. The results show that, the discrepancy (accuracy) between the GPS results and the precise leveling results are between 0.1&4.4 mm.

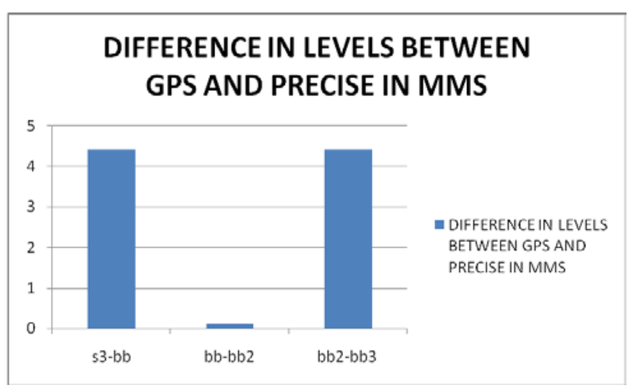

Fig. 16.Difference in vertical distance between the GPS results and the precise level after a GPS time interval of 20 minutes referenced to S1&S2

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
RMS of vertical displacement for all points at each time interval in mm

Time interval	5mins	10mins	15mins	20mins
Error in (S3-BB)	10.9	7.7	6.6	4.4
Error in (bb-bb2)	0.6	0.2	0.6	-0.1
Error in (bb2-bb3)	6.3	6	2.6	4.4
Root mean square error	12.60	9.76	7.11	6.22

Figure (17) 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 12.6mm at time interval of 5 minutes to 6.2 mm at time interval of 20 minutes.

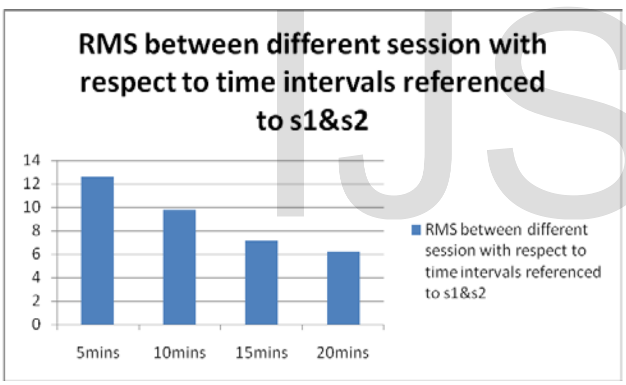

Fig. 17.RMS of all points during the GPS time interval referenced to receivers A &B

6 Conclusions

Based on the previous results between the precise level and GPS static data, the following conclusions can be drawn:

- The accuracy of measuring the vertical movement using relative static technique resulted from GPS compared every point with itself is from about (0.1 to 10.2mm)
- The accuracy of measuring vertical deformation of points on structure using relative static technique of GPS is from (0.2mm) to (20mm) and the best accuracy is for the 20 minutes time interval which reveals that moreover the time interval increase in the GPS, the accuracy increases.
- The root mean square error decreases as the time interval increases as the 20 minutes gave the best accuracy while the 5 minutes gave the least accuracy
- There is need to use two static receivers in measuring and monitoring of vertical structural deformations as the result of accuracy increase only by ratio 40% 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 must be compared in valuable way to that value of 40% increase in accuracy and its effects and accuracy needs.

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