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Establishment of New Continuous Operating Reference Station (CORS) at Faculty of Engineering, Ain Shams University

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Abstract*: In this work, establishment and operation of new Continuous Operating Reference Station (CORS), at Faculty of Engineering, Ain Shams University, Cairo, Egypt, will be discussed. In addition, tying this station to the Egyptian CORS network will be performed using 3 different positioning techniques. The first technique is the Precise Point Positioning (PPP), while the second is the Differential Global Navigation Satellite System (DGNSS) technique with respect to the International GNSS Service (IGS) stations. The third technique is the DGNSS positioning with respect to stations of the Egyptian CORS network. Solutions of the third technique will be used as reference coordinates to assess the quality of using the PPP or the IGS DGNSS techniques in tying new stations, observed at the present time, to the Egyptian CORS network. Both techniques will be assessed using GNSS data for 4 days in month June 2017. In addition, 24 hours observation periods and 4 hour observation periods (day hours and night hours) will be evaluated. GNSS data, for the same 4 days, for a number of stations of the Egyptian CORS network were obtained from the Egyptian Survey Authority (ESA) to be used in the third technique to derive reference coordinates in the assessment process. This study shows that the IGS DGNSS solutions achieved much better results than the PPP solutions. The IGS DGNSS solutions could get coordinates with mean horizontal positional difference 2.5cm in case of using 24 hours observation periods, 3.5cm in case of using 4 hours (day hours) observation periods and 2.8cm in case of using 4 hours (night hours) observation periods. Generally, using the IGS DGNSS positioning technique in tying new stations to the Egyptian CORS network can achieve very promising results and help to avoid many administrative restrictions and additional costs. Also, the 4 hours observation periods can achieve promising results which make it applicable to the different surveying works performed in Egypt.

***Index Terms*: CORS, DGNSS, IGS, PPP.**

I. INTRODUCTION

Many CORS networks were developed by a number of governmental, private and academic organizations to support the precise positioning and navigation for applications ranging from ordinary engineering work to robust target location identification and scientific research [1].

The Egyptian CORS network was established in 2011 and tied to a number of neighboring IGS stations adopting International Terrestrial Reference Frame 2008 (ITRF2008) epoch 2011.811 as its static datum. Consequently, coordinates tied to this datum don't change with time neglecting the effect of the tectonic plate motion.

The Egyptian CORS network comprises 40 stations covering the area along Nile Valley and the Delta as shown in Figure 1 [2].

Fig. 1. The Egyptian CORS Network

A new CORS was established at Faculty of Engineering, Ain Shams University, Cairo, Egypt in 2017 and was given the name 'SHMS'. The system components and operation of this station will be discussed in this study. In addition, tying this station to the Egyptian CORS network will be performed using different positioning techniques. Besides SHMS station, different surveying works in Egypt are required to be tied to the Egyptian CORS network. The direct way for this purpose is using the DGNSS technique with respect to the nearby stations of the Egyptian CORS network. This positioning process should be asked to be performed by ESA as it owns the coordinates and the GNSS observation data of these nearby stations which are not authorized and accessible for users. This process necessitates additional costs and faces administrative restrictions. This study discusses the different positioning techniques that can be used to tie new stations to the Egyptian static CORS network avoiding any administrative restrictions and additional costs. GNSS showed the capacity to deliver improved positioning services and accuracy due to the modernization of the satellite systems, significantly upgraded error estimation models, increased mobility for the end-user receivers and more reliable and rapid integer ambiguity resolution approaches [3].

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The coordinates of a single point can be determined using a single receiver which measures pseudoranges to (normally 4 or more) satellites. This positioning technique is called 'Single Point Positioning' or 'SPP' [4]. The relevant references always emphasize that SPP is suitable for navigation and not for surveying works as the positioning accuracy degrades to few meters due to the different biases caused by the ionosphere and troposphere signal propagation media, satellite clock and orbital data.

A breakthrough in the positioning field was the ubiquitous PPP technique. The IGS has ensured open access and high-quality GNSS data products since 1994. These products enable access to the definitive global reference frame for the different scientific and commercial applications. The IGS products include GNSS satellite ephemerides and satellite clock information which can be used to provide orbit/clock corrections for the PPP solutions.

A number of software packages can be used to process the GNSS data in the PPP processing mode. The used software in this study is RTKLIB which is an open source program package for standard and precise positioning with GNSS. RTKLIB employs Extended Kalman Filter (EKF) estimation process for the PPP mode [5]. Another positioning technique is the DGNSS positioning with respect to the IGS stations, with known coordinates, tied to the ITRF dynamic datum.

Both PPP and IGS DGNSS positioning techniques will be assessed in this study by comparing the obtained coordinates, using these techniques, to the coordinates that can be obtained by the direct way, if data for the Egyptian CORS network stations are available for any user. The assessment strategy in this study for both PPP and IGS DGNSS techniques relies on the newly established CORS at Faculty of Engineering, Ain Shams University. In addition to the assessment process of both techniques, the influence of changing the observation periods on the quality of tying will be evaluated. Consequently, 24 hours observation periods and 4 hour observation periods (day hours and night hours) will be evaluated in this study.

II. STATION DESCRIPTION

SHMS station was established at Faculty of Engineering, Ain Shams University in 2017, mainly, to provide the necessary GNSS data for different present and future research topics. The antenna monument was chosen to be above the main building of Faculty of Engineering, Ain Shams University, as shown in Figure 2, in order to get sufficient height to minimize obstructions and to avoid GNSS signal multipath.

Fig. 2. The Antenna Monument above the Main Building of Faculty of Engineering, Ain Shams University

This CORS uses a Trimble NetR9 GNSS reference receiver which offers 440 channels for GNSS multi-constellation tracking performance and supports a wide range of satellite signals. Currently, the NetR9 platform is capable of tracking signals from Global Positioning System (GPS), GLONASS, Galileo, Beidou and QZSS constellations [6].

Figure 3 shows the Trimble NetR9 GNSS reference receiver used with SHMS station.

Fig. 3. Trimble NetR9 GNSS Reference Receiver used with SHMS Station

The station receiver, in the control room, is connected with the antenna monument using cable, while the receiver is connected with the master computer to enable the external access of the received GNSS data. Data are stored using different modules to provide data with different epoch intervals; 1s, 5s and 30s. Other computers in the control room facilitate the backup process of the stored GNSS data. In addition, the stored data are archived using hard drives every 1 month. The flow chart, shown in Figure 4, summarizes the operation of SHMS station.

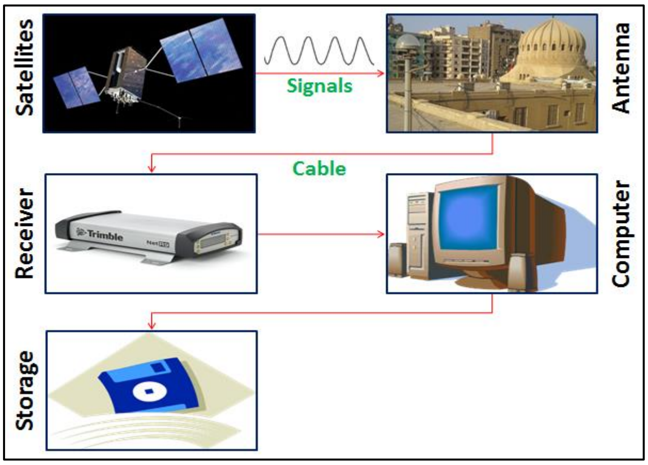

Fig. 4. Flow Chart Summarizing the Operation of SHMS STATION

III. THE USED IGS AND EGYPTIAN CORS NETWORK STATIONS

Five stations from the Egyptian CORS network participated in this study and they are: AYAT, CARO, ETSA, KBER and RMDN, shown in Figure 5.

Fig. 5. The used Stations from the Egyptian CORS Network, in Addition to SHMS Station

These stations were chosen as they are the nearest stations to SHMS station as shown in Figure 5.

The Receiver Independent Exchange Format (RINEX) data files for the five stations of the Egyptian CORS network were obtained from ESA for 4 days (1 June 2017, 4 June 2017, 6 June 2017 and 11 June 2017), such that each day has, at least, 3 available RINEX files for 3 different stations. Also, the RINEX data files for SHMS station, for the same days, were acquired.

For the IGS DGNSS technique, a number of neighboring IGS stations participated in this study. The chosen stations, to be involved in this study, are listed in Table 1.

Table 1. The chosen IGS Stations to be Involved in the IGS DGNSS Technique

Site	ID
NICOSIA-ATHALASSA	NICO
Noto	NOTl
Ohrid	ORID
Haifa	BSHM
Mitzpe Ramon	RAMO
Metzoki Dragot	DRAG

Figure 6 shows the location of the used IGS stations, in addition to SHMS station.

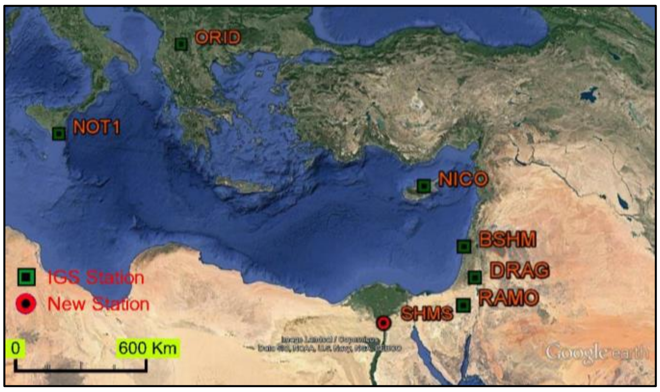

Fig. 6. The IGS Stations Involved in the Study, in Addition to SHMS Station

The IGS RINEX data files, for the chosen stations, and final orbits files, for the previously mentioned dates (1 June 2017, 4 June 2017, 6 June 2017 and 11 June 2017), were acquired from the Crustal Dynamics Data Information System (CDDIS) data center.

IV. STATION COORDINATES

A. PPP Solutions

Each day of the 4 previously mentioned days was processed in the PPP processing mode using RTKLIB software. In this mode, the RINEX files for only SHMS station were used without the need to any additional RINEX files for other stations. The IGS final orbits files were used, the Iono-Free Linear Combination (LC) was used as an ionosphere correction and Estimated Zenith Total Delay (ZTD) was used as a troposphere correction.

In order to evaluate the influence of changing the observation periods on the quality of tying, the processing sessions were repeated but this time, the observation periods were reduced from 24 hours to 4 hours. Consequently, another 8 sessions were performed for 4 hours observation periods; 4 sessions for observation periods in day hours from 8:00 AM to 12:00 PM and 4 sessions for observation periods in night hours from 8:00 PM to 12:00 AM.

The processed and adjusted coordinates of SHMS station, for each day and for the 3 different observation periods, using the PPP technique were derived. Table 2 shows the resulted errors for the processed coordinates, where $\sigma_{Lat.}$ is the error caused by the change in the latitude, $\sigma_{Long.}$ is the error caused by the change in the longitude and σ_h is the error in the ellipsoidal height.

TABLE 2. The Resulted Errors for the Processed Coordinates of SHMS Station in Case of using the PPP Technique

Day	Observation Period	$\sigma_{Lat.}\ (m)$	$\sigma_{Long.}\ (m)$	$\sigma_h\ (m)$
1-Jun	24h	0.001	0.002	0.004
	4h (day)	0.004	0.008	0.013
	4h (night)	0.003	0.007	0.011
4-Jun	24h	0.001	0.002	0.005
	4h (day)	0.004	0.008	0.013
	4h (night)	0.003	0.007	0.011
6-Jun	24h	0.001	0.002	0.005
	4h (day)	0.004	0.008	0.014
	4h (night)	0.003	0.007	0.011
11-Jun	24h	0.001	0.002	0.005
	4h (day)	0.004	0.008	0.014
	4h (night)	0.007	0.012	0.002

B. IGS DGNSS Solutions

The RINEX data files for the used IGS stations and SHMS station were processed together, using Trimble Business Center (TBC) software, to obtain the coordinates of SHMS station, tied to the IGS stations. It should be kept in mind that the coordinates of the used IGS stations should be referenced to ITRF2008 epoch 2011.811 as the Egyptian CORS network was tied to ITRF2008 at the same epoch. These coordinates were fixed as constraints in the processing stage and they could be acquired

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from the ITRF website [http://itrf. ensg.ign.fr/site_info_and_select/solutions_extraction. php].

Three processing sessions were performed for each day of the 4 previously mentioned days; one in case of using 24 hours observation period, another in case of using 4 hours (day hours) observation period and last one in case of using 4 hours (night hours) observation period. Each session includes the RINEX data files for SHMS station and the used IGS stations, in addition to the final orbits files for the same day.

The processed and adjusted coordinates of SHMS station, for each day and for the 3 different observation periods, using the IGS DGNSS positioning technique were derived. Table 3 shows the resulted errors for the processed and adjusted coordinates. It can be noticed that the values of $\sigma_{Long.}$ are, generally, less than the values of $\sigma_{Lat.}$ due to the distribution of the IGS stations, around SHMS station, in the east-west direction, unlike the situation in the north- south direction.

TABLE 3. The Resulted Errors for the Processed and Adjusted Coordinates of SHMS Station in case of using the IGS DGNSS Technique

Day	Observation Period	$\sigma_{Lat.}$ (m)	$\sigma_{Long.}$ (m)	σ_h (m)
1-Jun	24h	0.024	0.019	0.110
	4h (day)	0.106	0.041	0.208
	4h (night)	0.034	0.031	0.168
4-Jun	24h	0.018	0.016	0.091
	4h (day)	0.039	0.035	0.149
	4h (night)	0.024	0.025	0.134
6-Jun	24h	0.014	0.010	0.061
	4h (day)	0.017	0.013	0.073
	4h (night)	0.018	0.012	0.071
11-Jun	24h	0.020	0.014	0.081
	4h (day)	0.025	0.024	0.148
	4h (night)	0.045	0.020	0.116

C. DGNSS Solutions with respect to Stations of the Egyptian CORS Network

Prior to assessing the positioning techniques, reference coordinates that can be compared to other coordinates resulted from the used techniques need to be derived. For this purpose, the RINEX data files for the Egyptian CORS network stations and SHMS station were processed together to obtain the coordinates of SHMS station, tied to the Egyptian CORS network. The coordinates of the 5 stations of the Egyptian CORS network were obtained from ESA to be fixed in the processing stage as constraints.

To avoid any confusion about using different data tied to ITRF with other data tied to the World Geodetic System 1984 (WGS84), it should be noted that WGS84 (G1762) reference frame compared to ITRF2008 shows Root Mean Square (RMS) difference of one centimeter overall. Comparisons between the National Geospatial-Intelligence Agency (NGA) GPS precise ephemerides, referenced to WGS84 (G1762), and the IGS GPS precise ephemerides, referenced to ITRF2008, validate that the two reference systems are consistent. This indicates that these two reference frames are essentially identical with differences being statistically insignificant for most applications [7]. To tie SHMS station to the Egyptian CORS network, 4 processing sessions were performed for the 4 previously mentioned days. Each session includes SHMS station and 3 stations of the Egyptian CORS network to be processed in the DGNSS processing mode using TBC software. The processed and adjusted coordinates of SHMS station for each day were derived. Table 4 shows the resulted errors for each day.

TABLE 4. The Resulted Errors for the Processed and Adjusted Coordinates of SHMS station for Each Day

Day	$\sigma_{Lat.}$ (m)	$\sigma_{Long.}$ (m)	σ_h (m)
1-Jun	0.005	0.007	0.026
4-Jun	0.005	0.008	0.029
6-Jun	0.008	0.013	0.043
11-Jun	0.004	0.005	0.022

Finally, weighted means could be calculated for the processed and adjusted coordinates of SHMS station for the 4 days. The standard deviations of the resulted weighted means were found to be 0.001m, 0.001m and 0.005m for $\sigma_{Lat.}$, $\sigma_{Long.}$ and σ_h , respectively.

The resulted coordinates will be considered as the reference in the assessment process in this study.

V. ACCURACY ASSESSMENT

A. PPP Technique

The differences between the derived coordinates and the reference coordinates of SHMS station can be calculated.

In order to assess the quality in the horizontal and vertical components, separately, the differences between the geodetic coordinates will be considered instead of the Cartesian coordinates. The difference in the latitude ($\Delta\emptyset$) and longitude ($\Delta\lambda$) between the PPP derived coordiantes and the reference coordinates of SHMS station gives an indication of the quality of transformation in the horizontal component. On the other hand, the difference in the ellipsoidal height (Δh) gives an indication of the quality of transformation in the vertical component. Prior to evaluating the quality in the horizontal component, $\Delta\emptyset$ and $\Delta\lambda$ should be transformed to the equivalent distances in meters by multiplying their values in the equivalent distance to one arc second which vary from one station to another and can be calculated using the basic rules of geometric geodesy.

The resulted equivalent distances to one arc second, at this location, were found to be 30.793m and 26.784m in the latitude and longitude, respectively.

Finally, the following equation can be applied to get the difference in the horizontal component:

$$\Delta HZ \simeq \sqrt{\Delta\emptyset^2 + \Delta\lambda^{\,2}} \qquad (1)$$

Where

ΔHZ is the difference in the horizontal component in meters.

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$\Delta\emptyset$ is the difference in the latitude in meters.
$\Delta\lambda$ is the difference in the longitude in meters.

Table 5 shows the final results of ΔHZ and Δh, in addition to the positional difference (ΔP).

TABLE 5. The Resulted Differences in case of using the PPP Technique

Day	Observation Period	ΔHZ (m)	Δh (m)	ΔP (m)
1-Jun	24h	0.116	0.057	0.130
	4h (day)	0.266	0.209	0.338
	4h (night)	0.257	-0.086	0.271
4-Jun	24h	0.114	0.077	0.138
	4h (day)	0.276	0.349	0.445
	4h (night)	0.210	0.055	0.217
6-Jun	24h	0.117	0.043	0.124
	4h (day)	0.252	0.472	0.535
	4h (night)	0.167	0.076	0.183
11-Ju n	24h	0.111	0.023	0.113
	4h (day)	0.164	0.513	0.538
	4h (night)	0.156	0.055	0.165
Mean	24h	0.115	0.050	0.126
	4h (day)	0.239	0.385	0.464
	4h (night)	0.197	0.068	0.209

B. IGS DGNSS Technique

The differences between the IGS DGNSS derived coordinates and the reference coordinates of SHMS station could be calculated in the same way used with the PPP positioning technique.

Table 6 shows the final results of ΔHZ and Δh, in addition to the positional difference (ΔP).

TABLE 6. The Resulted Differences in case of using the IGS DGNSS Positioning Technique

Day	Observation Period	ΔHZ (m)	Δh (m)	ΔP (m)
1-Jun	24h	0.025	0.059	0.064
	4h (day)	0.025	0.046	0.052
	4h (night)	0.025	0.023	0.034
4-Jun	24h	0.027	0.025	0.037
	4h (day)	0.047	0.027	0.054
	4h (night)	0.021	0.017	0.027
6-Jun	24h	0.022	-0.003	0.022
	4h (day)	0.023	-0.021	0.031
	4h (night)	0.025	-0.021	0.033
11-Jun	24h	0.025	0.029	0.038
	4h (day)	0.045	0.059	0.074
	4h (night)	0.039	0.014	0.042
Mean	24h	0.025	0.029	0.040
	4h (day)	0.035	0.038	0.053
	4h (night)	0.028	0.019	0.034

VI. ANALYSIS OF RESULTS

At this stage, the results obtained by using the IGS DGNSS and PPP techniques are analyzed. The quality of both solutions in tying new stations to the Egyptian CORS network is assessed by comparing the resulted coordinates from both techniques to the reference coordinates. The results show that using the IGS DGNSS technique, to get reliable coordinates tied to the Egyptian CORS network, showed much better results than using the PPP technique.

The coordinates obtained from the IGS DGNSS technique achieved differences in the horizontal component ranging from 2.2cm to 2.7cm with mean value 2.5cm and RMS 2.5cm in case of using 24 hours observation periods. In case of using 4 hours observation periods (day hours), the horizontal differences ranged from 2.3cm to 4.7cm with mean value 3.5cm and RMS 3.7cm. On the other hand, using 4 hours observation periods (night hours) achieved differences in the horizontal component ranging from 2.1cm to 3.9cm with mean value 2.8cm and RMS 2.9cm.

Figures 7, 8 and 9 show statistics of the resulted differences in case of using the IGS DGNSS positioning technique for 24 hours, 4 hours (day hours) and 4 hours (night hours) observation periods, respectively.

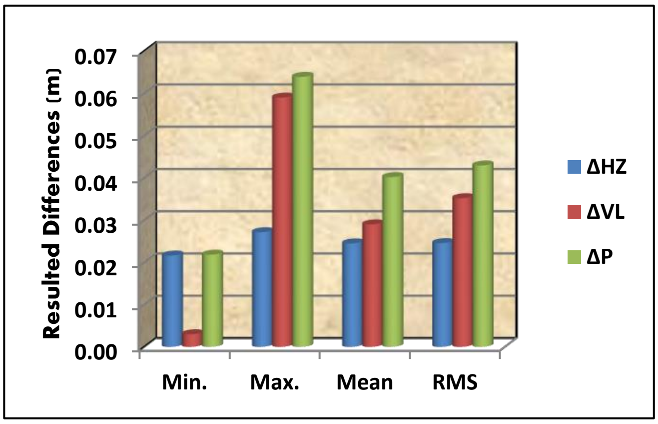

Fig. 7. Statistics of the Resulted Differences in case of using the IGS DGNSS Positioning Technique for 24 Hours Observation Periods

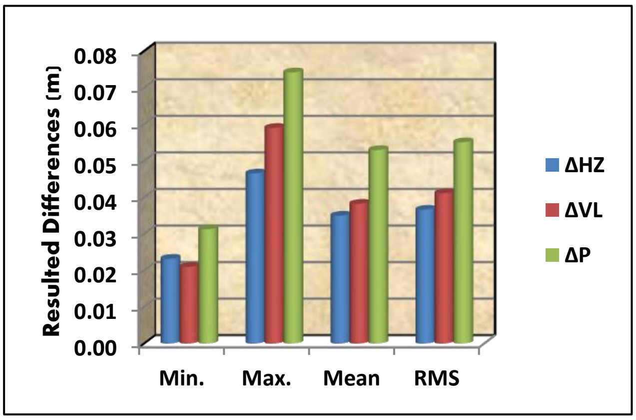

Fig. 8. Statistics of the Resulted Differences in case of using the IGS DGNSS Positioning Technique for 4 hours Observation Periods (Day Hours)

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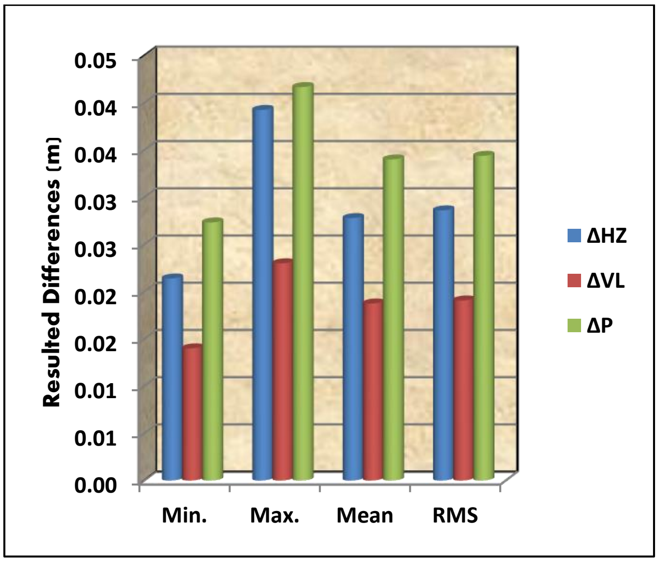

Fig. 9. Statistics of the Resulted Differences in case of using the IGS DGNSS Positioning Technique for 4 hours Observation Periods (Night Hours)

The coordinates obtained from the PPP technique achieved differences in the horizontal component ranging from 11.1cm to 11.7cm with mean value 11.5cm and RMS 11.5cm in case of using 24 hours observation periods. In case of using 4 hours observation periods (day hours), the horizontal differences ranged from 16.4cm to 27.6cm with mean value 23.9cm and RMS 24.3cm. On the other hand, using 4 hours observation periods (night hours) achieved differences in the horizontal component ranging from 15.6cm to 25.7cm with mean value 19.7cm and RMS 20.1cm.

The influence of changing the observation periods was significant in case of using the PPP technique, unlike the IGS DGNSS positioning technique. The quality of the obtained coordinates in case of using the PPP technique, with 4 hours (day hours) observation periods, deteriorated largely.

Figures 10, 11 and 12 show statistics of the resulted differences in case of using the PPP technique for 24 hours, 4 hours (day hours) and 4 hours (night hours) observation periods, respectively.

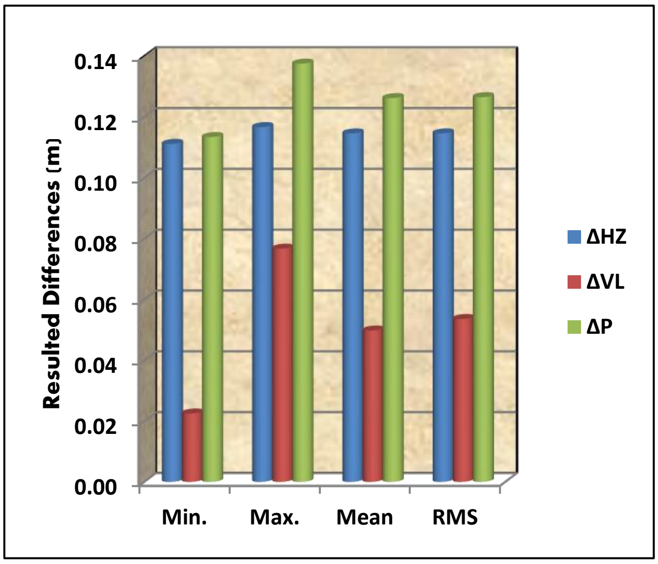

Fig. 10. Statistics of the Resulted Differences in case of using the PPP Technique for 24 Hours Observation Periods

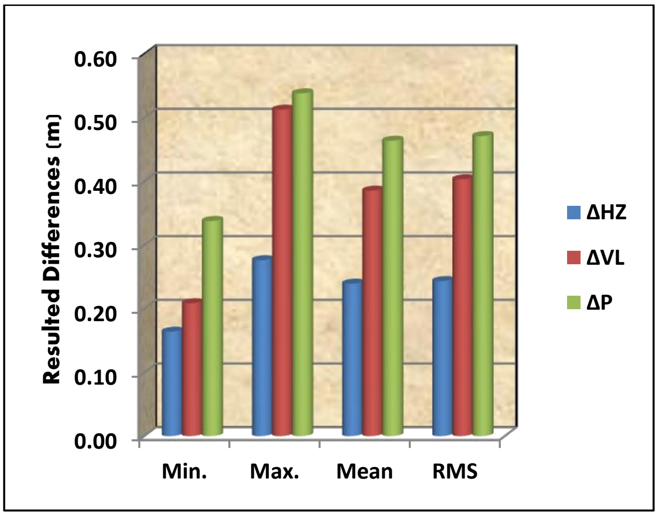

Fig. 11. Statistics of the Resulted Differences in case of using the PPP Technique for 4 Hours Observation Periods (Day Hours)

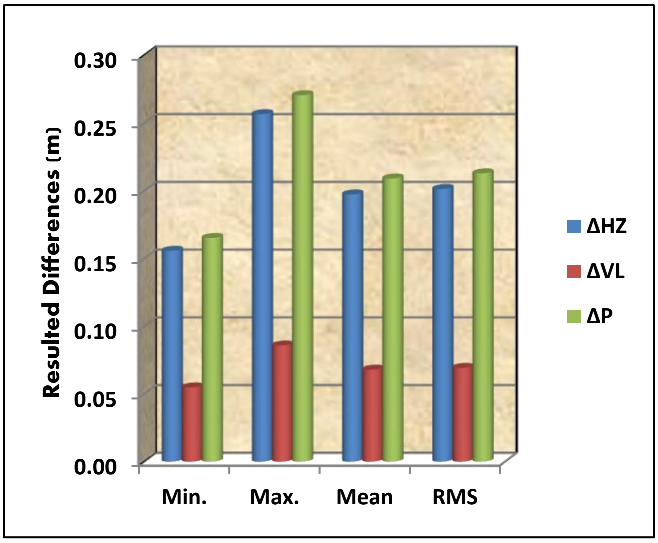

Fig. 12. Statistics of the Resulted Differences in case of using the PPP Technique for 4 Hours Observation Periods (Night Hours)

One factor that should be kept in mind, while assessing the PPP technique, is that the positioning process was performed in June 2017, while the Egyptian CORS network is tied to the static datum ITRF2008 epoch 2011.811. This difference in the epoch definition, certainly, had a significant effect on the quality of the obtained coordinates due to the effect of the tectonic plate motion that causes the coordinates of any point to change continuously over years. Generally, the promising results obtained by the IGS DGNSS positioning technique can help to avoid many administrative restrictions and additional costs to tie any new stations to the Egyptian CORS network. Also, the 4 hours observation periods achieved promising results which make it applicable to the different surveying works performed in Egypt. However, there is one drawback in using this approach and it is the latency for, at least, 12 days to be able to acquire the final orbits files from the data center.

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VII. CONCLUSION

The establishment and operation of new CORS, at Faculty of Engineering, Ain Shams University, Cairo, Egypt, were discussed. In addition, tying this station to the Egyptian CORS network were performed using 3 different positioning techniques.

The IGS DGNSS and PPP techniques, that can be used to tie new stations observed at the present time to the Egyptian CORS network, were assessed. Both techniques were assessed using GNSS data for 4 days in month June 2017. In addition, 24 hours observation periods and 4 hour observation periods (day hours and night hours) were evaluated. GNSS data, for the same 4 days, for a number of stations of the Egyptian CORS network were obtained from ESA to be able to derive coordinates that can be used as the reference in the assessment process. The results showed that:

- The IGS DGNSS solutions achieved much better results than the PPP solutions.
- The coordinates obtained from the IGS DGNSS technique achieved differences in the horizontal component with mean values 2.5cm in case of using 24 hours observation periods, 3.5cm in case of using 4 hours observation periods (day hours) and 2.8cm in case of using 4 hours observation periods (night hours).
- The coordinates obtained from the PPP technique achieved differences in the horizontal component with mean values 11.5cm in case of using 24 hours observation periods, 23.9cm in case of using 4 hours observation periods (day hours) and 19.7cm in case of using 4 hours observation periods (night hours).
- The influence of changing the observation periods was significant in case of using the PPP technique, unlike the IGS DGNSS positioning technique.

Generally, the promising results obtained by the IGS DGNSS positioning technique can help to avoid many administrative restrictions and additional costs to tie any new stations to the Egyptian CORS network. Also, the 4 hours observation periods achieved promising results which make it applicable to the different surveying works performed in Egypt.

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