GPS Levelling Without Geoid in Egypt Applied to Borg El-Arab City

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Contents

1. Introduction (orthometric heights by levelling)

- Levelling is a difficult task to determine orthometric heights.
- Levelling network covering all parts of the country would be impractical from the financial point of view.
- Levelling accuracy may be taken 6mm√Lkm for engineering applications it.
- Levelling over areas with rough terrain is very tough and time consuming.
- Levelling network status indicates that significant number of benchmarks have been destroyed and some of them have been exposed to unknown vertical deformation.
- Levelling network in Egypt has constrained the development in different areas, and initiated the necessity of using other techniques due to the problems of adding, replacing, monitoring, and maintaining of it.

1. Introduction (GPS levelling)

- GPS Levelling combines ellipsoidal height by GPS by geoidal height to determine orthometric height by: $H = h - N$
- GPS levelling may replace conventional spirit levelling and thus make the levelling procedure cheaper and faster.
- GPS levelling accuracy reflects the ellipsoidal and geoidal heights acc.
- Ellipsoidal heights by DGPS (dual frequency) are accurate enough because of the availability of satellites, more accurate satellite orbits, improved antenna designs, and improved data processing techniques
- Geoidal heights are less accurate and thus affecting accuracy of O.H.
- Geoidal heights can be determined by the global geopotential models alone or combined with the local gravity data i.e. gravimetric geoid.
- Geoidal heights can be used to determine geometric geoid model, by measuring h_i on several points (i) with known orthometric heights H_i

1. Introduction (GPS Levelling in Egypt)

- GPS Levelling in Egypt is urgently recommended as alternative to levelling.
- The lack of dense gravity data has restricted the production of accurate geoid model.
- The gravimetric geoid determination in Egypt has been done through the combination of global models with the available scattered gravity.
- The results are not accurate enough to support the GPS levelling.
- To produce an accurate local geoid for Egypt, it has been recommended to measure more gravity data spaced by 5km .
- This would be impractical financially and result in inaccessible points due to rough trerrain of many areas in Egypt.
- The suitable areas to add more gravity data (accessible areas) are the same areas covered with levelling network.
- The possible way to have an accurate geoid model would be a local geoid model at areas with available dense gravity data.

Objectives

- To define the areas in Egypt with gentle geoid slope which reflect small geoidal heights variation within the allowable levelling accuracy or even more, in case of no solution. " Concept of no geoid".
- To use the recent global model i.e. GRACE complete to degree and order 200 to determine the accurate long wavelength contribution of geoid model in Egypt.
- To use GPM98A Model complete to degree and order 1800 to estimate the short wave length contribution of the geoid model.
- To merge two models to produce global geoid for Egypt.
- To examine the concept of no geoid for Borg El-Arab city as one of new urban communities cities with area 50000 fed.

Objectives

- To define the geoidal heights at benchmarks distributed around and inside Borg El-Arab (48 points).
- To compare among the global geoid models i.e. GPM98a, EGM96, GRACE to support GPS levelling in geoidal heights determination.
- To generate geometrical geoid for Borg El-Arab city based on 48 benchmarks..
- To enhance the orthometric heights obtained by GPS levelling using geometric geoid.

2. Geoidal Heights Computed from Global Geoid Models

- Global geoid models represent the long wavelength part of the gravity field and are obtained from global geopotential solutions .
- To compute a geoidal height value N_{GM} we use the following formula:

$$N_{GM} = \frac{T}{\gamma} = \frac{GM}{r\gamma} \sum_{n=2}^{\infty} \left(\frac{a}{r}\right)^n \sum_{m=0}^{n} (\bar{C}_{nm} \cos m\lambda + \bar{S}_{nm} \sin m\lambda) \bar{P}_{nm}(\cos\theta)$$

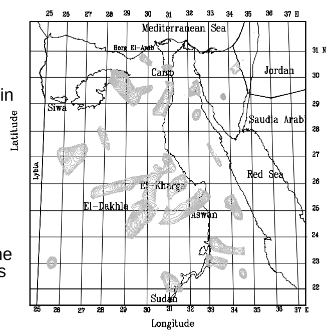
- Three global models were used i.e. GPM98A , GRACE, and EGM96.
- The ultra high degree geopotential model GPM98A, complete to degree and order 1800and resolution 10 km, was computed by Wenzel from world sets of 5' x 5' mean free air gravity anomalies.
- The GRACE gravity model GGM01C complete to degree and order 200 is a combination among Satellite gravity model only GGM01S and surface gravity data , altimetric sea surface heights. GGM01S was estimated with 111 days (spanning April through November of 2002) of GRACE K-band range rate , attitude , and accelerometer data.
- EGM96 is complete to degree and order 360.

3. GPS levelling Without Geoid

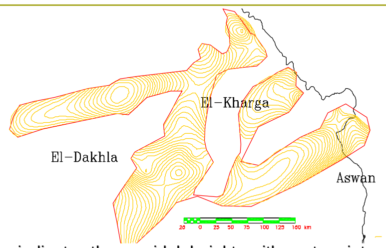
- To find out the areas in Egypt with flat geoid or with minimum geoidal height slope or to consider the concept of no geoid .
- The geoidal height variation should be within the allowable levelling error i.e. 6mm√km or even more, depends on the possible solutions for orthometric height problem.
- The geoidal heights for this application were determined from global models.
- GRACE model is known to be accurate to determine the long wavelengths of geoid, but it is unsuitable for the short wavelengths.
- The GPM98A model was used to compute the short wavelengths.
- The two models were combined to enhance the long wavelengths by GRACE model and to add the short wavelengths from GPM98A.

3. GPS levelling Without Geoid

- A contour map with contour interval 2 cm is prepared to show the areas where the geoid slopes seems to be nearly flat.
- Most of the areas are located in the western desert.
- The areas are in El-Wadi El-Gadid, Aswan, and Al-Fayom.
- The area around the Cairo – Alexandria desert road also indicates gentle geoid slope.
- The area north of Cairo and the area at the eastern boundaries are with nearly flat geoid.



3. GPS levelling Without Geoid



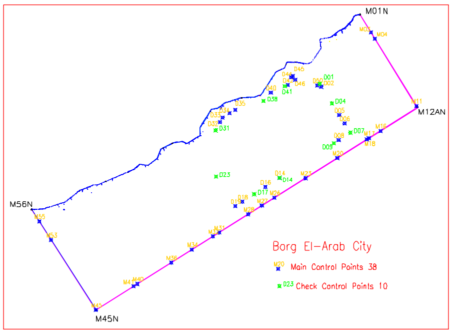
The figure indicates the geoidal heights with contour interval 2 cm

- One has to collect all the information about the new projects and decides the method of obtaining orthometric heights based on the required accuracy.

4.Testing Geoid from Global Models and Local “Geometric” Geoid to Support GPS Levelling in Borg El-Arab City

- The main Objective for the survey at Borg El-Arab city was to establish control points to be a base for map production and future planning.
- The horizontal control was performed using GPS (dual frequency).
- The vertical Control was suggested by using the levelling technique.
- The time and cost to finish such task was out of the planned issues.
- GPS levelling was used instead and tested based on the available global geoid.
- 48 points tied to the national vertical datum in and around the city were observed by dual GPS to determine ellipsoidal heights.

4.Testing Geoid from Global Models and Local "Geometric" Geoid to Support GPS Levelling in Borg El-Arab City



4.Testing Geoid from Global Models and Local "Geometric" Geoid to Support GPS Levelling in Borg El-Arab City

- The global geopotential models for GRACE complete to degree and order 200, EGM96 (360), and GPM98A (1800) were used to compute the geoidal heights for each point. The orthometric heights for the 48 points were estimated using GPS levelling basis.
- The errors in the GPS levelling orthometric heights compared to levelling orthometric heights were estimated.
- The errors were estimated for case of no geoid. The results indicate that the errors range between -12 cm to 18 cm . The standard deviation estimated for the results indicates that the GPM98A model gives minimum errors compared to the other models.

Table 4.1 Comparison of Errors in Orthometric Heigts Determined by GPS Levelling Based on Global Models and Levelling Orthometric Heights for 48 Points at Borg El-Arab City

Geoid Model	Min. (cm)	Max. (cm)	Mean (cm)	Std (cm)
No Geoid	-11.2	8.6	2.2	5.4
GRACE	-11.7	8.6	-.1	5
EGM96	-7.4	17.6	4.7	5.9
GPM98A	-10.7	3.6	-4.7	3.9

- The figures do not show fixed pattern for the errors i.e. no specific increase or decrease in one direction.

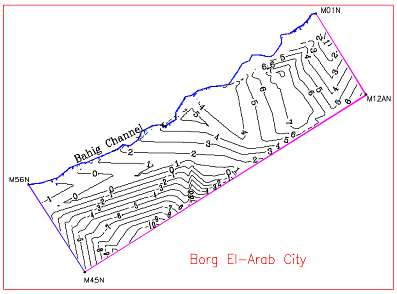


Figure 4.1 Error inOrthometric Heigts Determined by GPS Levelling Based on No Geoid Compared to Levelling Orthometric Heights for 48 Points

- The resulting errors are in the order of some centimetres and do not seem appropriate to replace classical levelling by GPS levelling, but with refined observation and data analysis techniques it certainly will.

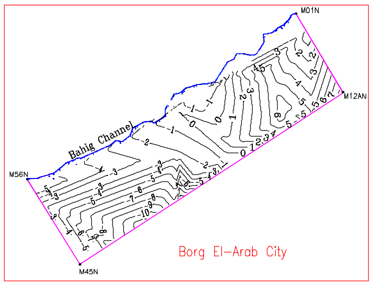
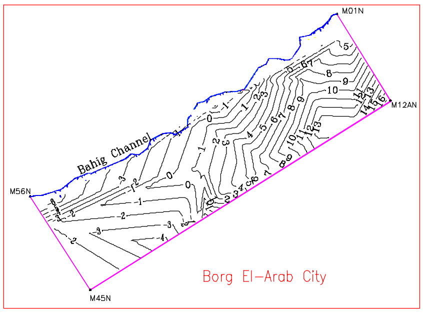
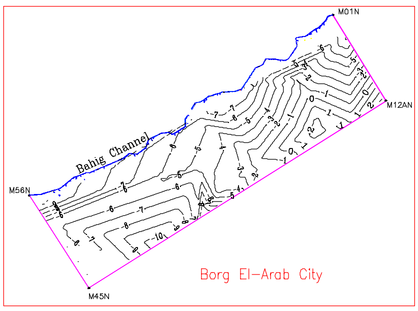


Figure 4.2 Error inOrthometric Heigts Determined by GPS Levelling Using Global Model GRACE Compared to Levelling Orthometric Heights for 48 Points



- Figure 4.3 Error inOrthometric Heigts Determined by GPS Levelling Using Global Model EGM96 Compared to Levelling Orthometric Heights for 48 Points



- Figure 4.4 Error inOrthometric Heigts Determined by GPS Levelling Using Global Model GPM98A Compared to Levelling Orthometric Heights for 48 Points

4.Testing Geoid from Global Models and Local "Geometric" Geoid to Support GPS Levelling in Borg El-Arab City

- The concept of local "geometric" geoid or corrector surface is applied here using the geoidal heights computed at 48 points with known O.H.
- Only 38 points were used to develop a corrector surface. The rest 10 points were used to test the various used models.
- The development of corrector surfaces aims at providing GPS users with an optimal transformation model between ellipsoidal heights h and orthometric heights H with respect to a given levelling datum.
- The SURFER software package version8.0 was used in the modelling
- Four models were used to choose the appropriate corrector surface.
- The triangulation with linear interpolation, polynomial regression, kriging, and inverse distance methods were used to model the errors or to define the corrector model.

4.Testing Geoid from Global Models and Local "Geometric" Geoid to Support GPS Levelling in Borg El-Arab City

- The Kriging method proves to be the best corrector surface.
- The residuals are in the range of one centimetre .
- The method of GPS levelling without geoid has proven to be effective by using the concept of producing local geometric geoid or producing corrector surface

Table 4.2 Comparison of Some Methods for Modelling of Errors in Orthometric Heights obtained from GPS Levelling in Case of No Geoid

Error Modelling Method	Min. (cm)	Max. (cm)	Mean (cm)	Std (cm)
Tringulation with linear Interpolation	-0.33	1.82	0.42	0.76
Polynomial Regression	-0.91	4.10	1.93	1.53
Kriging	-0.44	1.08	0.26	0.59
Inverse Distance	-0.74	1.73	0.51	0.74

5. Conclusions

- GPS levelling technique has the potential to replace the classical levelling in orthometric height determination.
- By this technique, it would be possible to determine the orthometric heights in less time and cost than the traditional technique.
- The accuracy of GPS levelling orthometric heights depends mainly on the accuracy of used DGPS and geoid model.
- The concept of using no geoid is introduced, based on merging the global geopotential models GPM98A and GRACE to produce geoid.
- The areas with gentle geoid slopes were determined where GPS levelling may be used without geoid information.
- The criteria used in such classification was to define the areas with geoidal variation do not exceed 2cm in distances more than 5km.
- The areas are mainly located in Western desert , especially at El-Wadi El-Gadid governorate.

5. Conclusions

- The GPS levelling technique was also applied at Borg El-Arab city.
- The global geoid models were tested to support GPS levelling in producing orthometric heights.
- The GPM98A model produces small errors compared to the others.
- The global models do not improve the errors of orthometric height resulted from GSP levelling.
- The concept of using geometric geoid or corrector surface was used. Four models i.e. the triangulation with linear interpolation, polynomial regression, kriging, and inverse distance methods were tested as corrector surfaces .
- The kriging method produces minimum residuals compared to the others. The residuals after using corrector surface indicate that the GPS levelling is capable to replace the traditional levelling.

Thank you