Potential of the Iranian Geoid For GPS/Leveling

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ABSTRACT

We know that leveling survey is a slow, expensive, and labor intensive operation and especially in Iran until today we try to complete only the first order-leveling network. It is obvious that we need the second and three-order network for civil engineering project but it need several years. In this research in order to getting the absolute and relative accuracy of the Iranian gravimetric geoid in GPS/leveling, I selected 55 points of Global Positioning System (GPS) network with stations of Iranian first order leveling network in different parts of the country. For studying the effect of topography and gravity data coverage in geoid accuracy I also select five separate traverses in different parts of the country from these points. According to the results of this research the absolute accuracy is estimated as 1.56 m; similarly, for the five selected profiles, the results was in the range of 0.90 m to 1.92 m.

The best results are seen in the west and center of the country (0.90 and 0.91 m respectively) and the worst in the north and south-east (1.92 and 1.27) respectively). It can be clearly known that these areas have the greatest leak of gravity points. To test the relative accuracy of the geoid, I computed relative geoidal undulations of all possible baselines and separately for the five above selected profiles. The average relative accuracy of geoid is 36 ppm using 55 points and 21.3 - 57.7 ppm for the five selected profiles for average baseline length. The worst results again were obtained in the north and southeast of country (35.2 and 57.7 ppm). Finally In order to improve and absorbing the long-wavelength errors of geoid, I used one transformation model between the gravimetric geoid and GPS/leveling derived geoid. According to the results of research GPS/Leveling technique can be replace for three and specially forth order leveling (civil engineering purpose) instead of regular spirit leveling surveying in the most regions of country.

0 - INTRODUCTION

Today the GPS technique has been used for leveling projects, e.g., to monitor dam subsidence due to water or natural gas removal, earth crustal movements and to control heights across water bodies in connection with bridge construction and for many applications, conventional leveling using spirit level is being replaced by height determination using the satellite Global Positioning System (GPS).

The aim of this research is to test the potential of the Iranian gravimetric geoid and estimating objectively its absolute and relative accuracy for this purpose. Starting by reviewing the present Iranian gravimetric geoid properties, it's main sources of information, computational procedures and the internal estimation of accuracy, and then by analyzing the geodetic heights of the 55 GPS stations co-located with benchmarks of the national first order leveling network and computing the GPS/leveling-derived geoidal undulations at these locations. Then absolute and relative accuracies of these geoidal undulations are estimated and the results are discussed and interpreted. By the estimation of the external (absolute and relative) accuracy of the gravimetric geoid using GPS/leveling and a global geoid solution, all the comparisons and subsequent an improvements are carried out in five different topographical regions of Iran. This allows us to discuss the importance of gravity data distribution in the computation of the gravimetric geoid as a function of topography. Recapitulating the conclusions and offering some recommendations come in the last.

1- Iranian Geoid Determination

Iranian geoid computation was carried out in two stages: the first stage was conducted in 1986 jointly by the Institut fur Angewandte Geodasie (IfAG), the Institute of Geophysics, Tehran University (IGTU) and the National Cartographic Center of Iran (NCC), using geopotential model improvement method based on GPM2 global geopotential model [1]. In the second stage (conduced in 1990), the group used a new improved Digital Terrain Model (DTM) of Iran on a one sq. Km grid [2] and the OSU89B [3] as a new global geopotential model with the same gravity information as used in the first stage. In this stage, IfAG and NCC group used the remove-restore technique for the transformation of gravity anomalies (Δg) to geoidal undulations (N) and computed the integral formulas with the FFT approach [2]. The Institute of Geophysics of Tehran University (IGTU) made available the observations of about 12,000 Iranian gravity points (for their distribution see Figure (1). These data are observed after 1960 by IGTU and other organizations, e.g., by the Iranian National Geographic Organization in cooperation with the US Army Topographic Command [4].

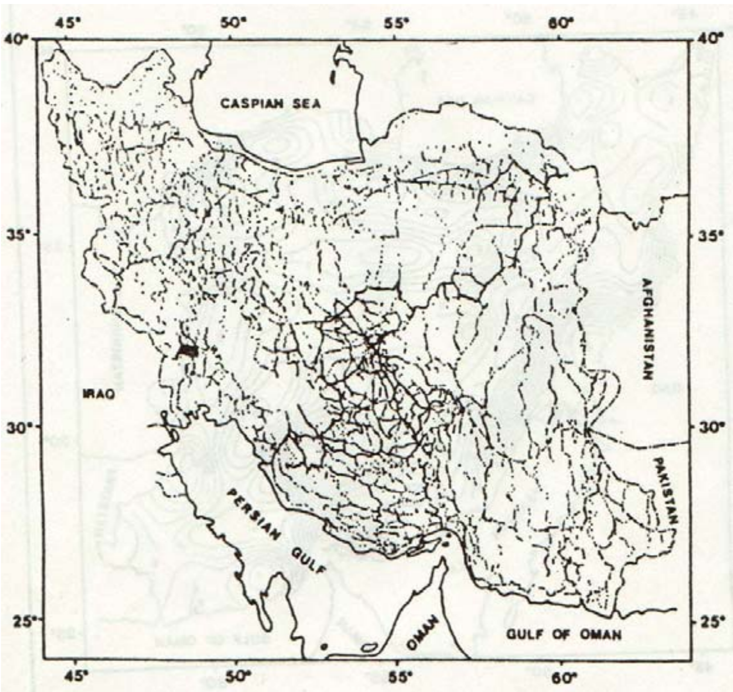


Figure (1). Distribution of Iranian gravity points.

These data are connected to the 1st and 2nd order gravity networks of the country then earth tide and drift corrections had been applied, separate least squares adjustments are carried out to obtain the results from individual campaigns [5].

2- TESTING THE GRAVIMETRIC GEOID

2-1- GPS Derived Geoidal Heights N (GPS)

Coordinate determination from GPS measurements uses the known positions of satellites and the measured distances between satellites and the unknown points. In principle, this methodology applies to both point and relative (differential) positioning. The heights directly derived from GPS measurements are geodetic heights referred to the ellipsoid defined by WGS84. In the following discussion, therefore concentration is made on the transformation of geodetic heights into orthometric heights. Figure 2 shows the basic relationship between geodetic height, h, and orthometric height, H. in the first approximation, the heights are related by

$$h = H + N \quad (1)$$

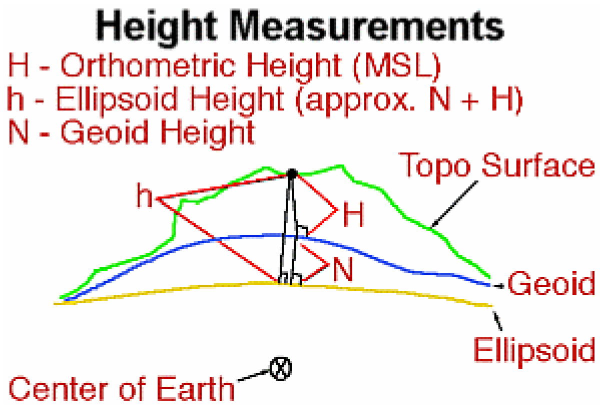


Fig2. Basic relationship between geodetic height, h, and orthometric height

The problem of transforming GPS-derived ellipsoidal heights into orthometric heights thus reduces
to the determination of geoidal undulations, which involves a combination of satellite and terrestrial gravity measurements or other data. A testing of available geoid solutions can be carried out using ellipsoidal heights from GPS observations and corresponding orthometric heights from leveling. The GPS measurements of Iranian GPS network started in August 1988 and continued through 1990, using three WM101 receivers. Each triangle was measured in one session (day or night) and the receivers located on the each vertex, received data from at least four satellites simultaneously for a period of three hours. In the next session, receivers were moved to another vertices of the next triangle until the whole network was covered [6]. The "Sky" software (Leica group production, 1993) was used for the computation of single point positioning as well as for baselines.

According to the primary result of adjustment of the national GPS network [7], the mean accuracy of the geodetic height (h) equals to:

$$\bar{\sigma}(h) = 0.21 \text{ m.} \quad (2)$$

The geoidal height N(GPS) is obtained from

$$N (GPS) = h - H. \quad (3)$$

Where the orthometric heights H originate from the 1st order national leveling network. Spirit leveled heights are believed to be accurate only at the 0.7 m (or worse) level, because of the following reasons:

1. Neglecting the "sea surface topography" in the 1989 adjustment of leveling networks [8]. According to a recent research the SST can be approximated at most at the 20-cm level [9].

2. The presence of systematic error, e.g., refraction, staff settlement, etc. on the leveling observations used in the adjustment of the network.

3. Failing to take into account the effect of gravity on height [8].

4. There is some uncertainty in the absolute accuracy of the leveling point considered by NCC as the height reference in the adjustment of the network [8].

According to technical report published by NCC [8], the average accuracy of ΔH for the first order national leveling network is equal to 3ppm but due to the noted problems and a recent research [10] this value appears unrealistic.

Figure (3) and (4) show a thematic map of topography of Iran and the location of the five selected traverses. In these figures, the stations are been distributed geographically in an irregular pattern with an average separation of a hundred km in the different topographical areas.

For geoid undulations given by eqn. (3), the law of error propagation gives

$$\sigma N(GPS) = \mathrm{Sqrt}\,(\sigma h^2 + \sigma H^2) \qquad (4)$$

By substitution for σH and σh from (2) and (3) results in

$$\sigma N\,(GPS) = 0.73\ \mathrm{m} \qquad (5)$$

This value is then used in all subsequent computations.

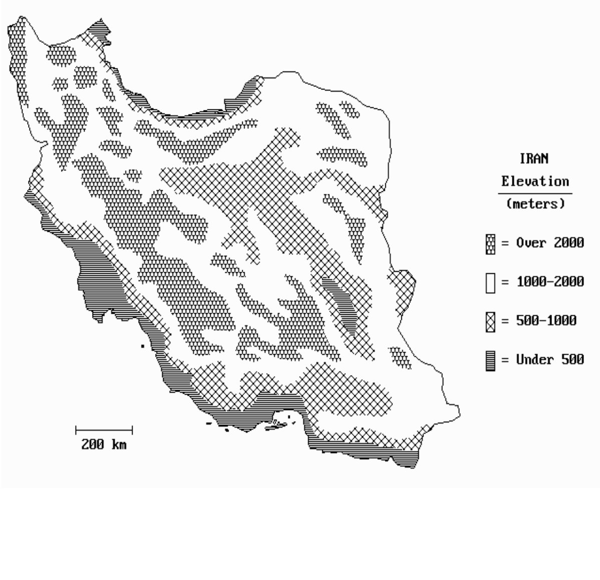


Fig. (3). thematic map of topography of Iran.

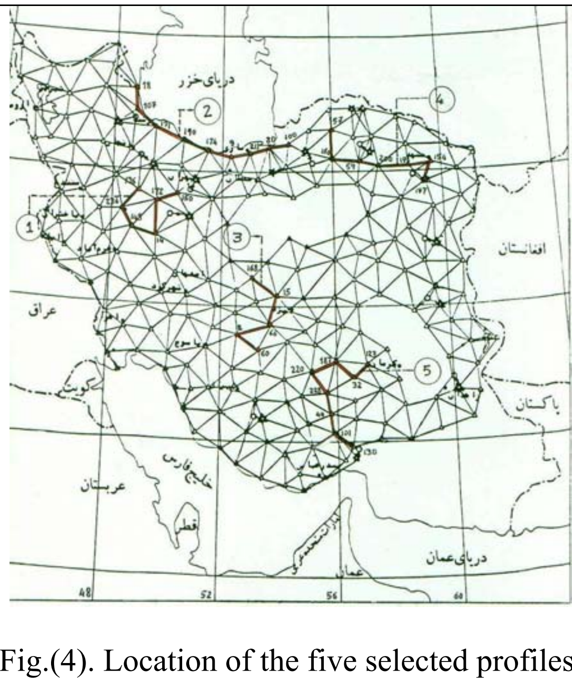


Fig.(4). Location of the five selected profiles.

3-ESTIMATION OF ABSOLUTE ACCURACY

To test the accuracy of gravimetric geoid, first all 55 points were analyzed all together then five GPS traverse networks in the north, west, east, south-east and center of Iran were selected. The aim of choosing these five traverses in different of areas is the study the effect of topography and gravity data coverage on the absolute and relative accuracy of the IfAG geoid.

Further I used 515 * 512 girded 110 " * 160 " file of the second step Iranian geoid for the interpolation of N (FFT). In table (1) I give information of the five GPS/leveling traverse. By studying Fig. (1) it is seen a great leak of gravity data in the north and southeast of the country so it is understandable that we get the least accuracy in these areas. For determination of σN (FFT) we have:

$$N (FFT) = N (GPS) - \delta N \quad (6)$$

And so there is

$$\sigma N(FFT) = Sqrt (\sigma\delta N^2 + \sigma N^2 (GPS)) \quad (7)$$

For the statistical analysis of the fit of the two data sets, say N (GPS) and N (FFT), following statistics Are used:

$$\sigma\delta N = Sqrt \left[\sum_{i=1}^{n}(\delta N - mean (\delta N))^2 / n\right] \quad (8)$$

Referring to equ. (8), and table (1) the bias reduced RMS. Of difference of N (FFT) and N (GPS) equals to 1.38 m. By substituting equ. (5) into equ. (7) We get the absolute accuracy of IfAG computed geoid as:

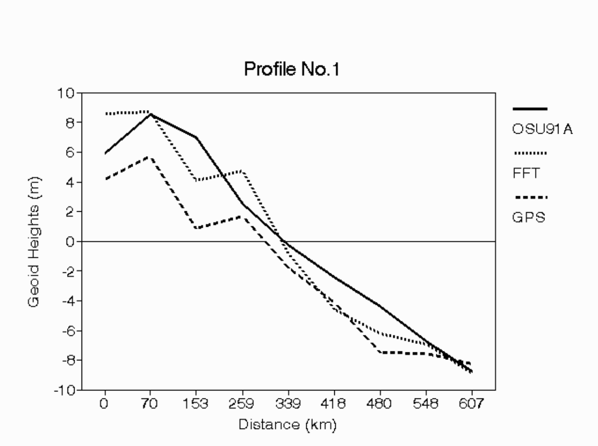
$$\sigma N(FFT) = 1.56 \text{ m} \quad (9)$$

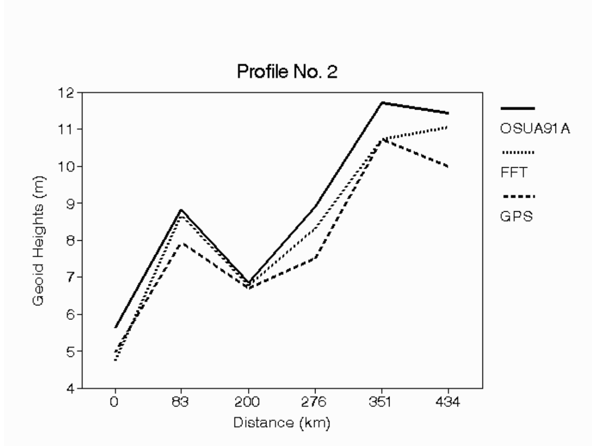
Table (1). Absolute geoid information of five GPS/Leveling profiles(m).

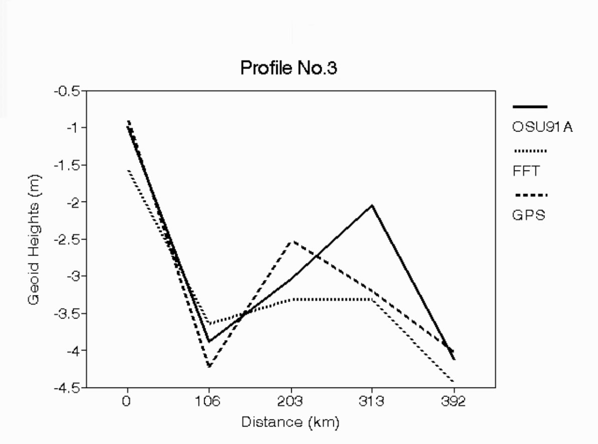
LOCATION	STATISTIC	δN OSU/FFT	δN OSU/GPS	δN FFT/GPS	σδN
PROFILE NO. 1 WEST	MEAN	0.5	0.9	0.41	0.9 m
	RMS	0.37	0.47	0.52	
	MIN	0.08	0.15	-0.23	
	MAX	0.99	1.43	1.06	
PROFILE NO. 2 NORTH	MEAN	0.3	2.01	1.71	1.92 m
	RMS	1.86	1.87	1.78	
	MIN	-2.65	-0.52	-0.66	
	MAX	2.92	6.1	4.45	
PROFILE NO. 3 CENTER	MEAN	044	0.15	-0.28	0.91 m
	RMS	0.55	0.63	0.55	
	MIN	-.025	-0.51	-0.79	
	MAX	1.26	1.15	0.58	
PROFILE NO. 4 EAST	MEAN	0.10	-0.45	-0.66	1.12 m
	RMS	1.45	1.09	0.86	
	MIN	-1.78	-2.14	-1.74	
	MAX	2.08	0.86	0.48	
PROFILE NO. 5 SOUTH-EAST	MEAN	0.27	-0.95	-1.25	1.27 m
	RMS	1.76	1.42	1.04	
	MIN	-1.71	-3.05	-2.88	
	MAX	3.76	1.36	0.35	
IRAN					1.56 m

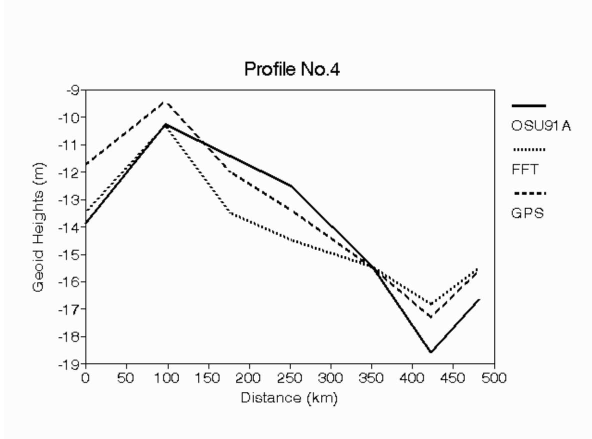
For the five selected profiles similarly using the RMS for Table (2) we get σN (FFT) with the range of 0.90 m to 1.92 m. The best results are obtained in the West and center of the country (0.90 and 0.91 m respectively) and the worst in the north and south-east (1.92 and 1.27 respectively). Using Fig. (1) distribution of gravity points it can be clearly seen that in these areas we have a great leak of gravity points. The standard deviations of the gravimetric geoidal heights can be expressed as:

$$\sigma N(FFT) = Sqrt\,(0.63^2 + \sigma\delta N\,(FFT)^2) \qquad (10)$$









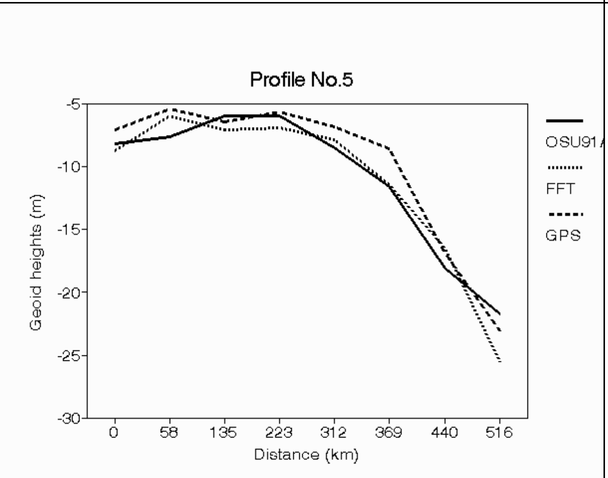


Fig.(5). Comparison of thedifferent geoid solutions along the five GPS/leveling traverses.

Where 0.63 m is the total long-wave error to be expected from the use of OSU89B. So the accuracy of the local gravity and topography data could be computed as:

$$\sigma\delta N\ (FFT) = 1.43\ m \qquad (11)$$

In figures (5) I give the comparison of the different geoid solutions along the five GPS/leveling traverses. The solid line represents the results obtained using the OSU91A geopotential model only, the dotted line (labeled FFT after the mathematical techniques used) symbolizes the results obtained by combining the GM with terrestrial gravity and height data and the dashed line represents GPS/leveling derived geoid. According to the figures, the GPS/leveling derived geoid fits the FFT geoid better than the OSU91A geoid in all selected areas.

4- ESTIMATION OF RELATIVE ACCURACY

To test the relative accuracy of the geoid, relative geoidal undulations ΔN for of the all five profiles, for each baseline defining were computed. Therefore,

$$\delta\Delta N = \Delta N\ (FFT) - \Delta N\ (GPS) \qquad (12)$$

So

$$\sigma\Delta N\ (FFT) = \text{sqrt.}\ [\sigma\delta\Delta N^2 + \sigma\Delta N^2\ (GPS)] \qquad (13)$$

In this case we are interested the ratio, σΔN (FFT) i / Di, where Di is the length of the baselines. It is common to express this ratio in parts per million, or "ppm". It is concluded that the IfAG geoid provides an average 35.75 ppm accuracy for all selected baselines (using 55 points) and 21.32 - 57.66 ppm for the five selected profiles. In this case also I get the worst results in the north and southeast of the country (16 and 26.5 ppm) (tables 2-a and b).

5- improving the Geoid Fits

The gravimetric geoid do not agree with the GPS/leveling derived geoid to better then 1.56 m, The source of the long-wavelength errors could be geopotential model errors or bad gravity coverage (since the north and south-east of the country are not well covered), bad elevation datum for the gravity observations (since barometric leveling was mostly used), systematic errors in the differential leveling, and problems in the GPS datum. To absorb such errors, I have considered general transformation, which represents a translation, rotation, and scale change of the GPS coordinate system. The corresponding effect on the geoid would be of form:

$$N' = N + a1 + a2.\cos(\varphi).\cos(\lambda) + a3.\cos(\varphi).\sin(\lambda) + a4.\sin(\varphi) \qquad (14)$$

Where a1 to a4 are some constants [15] to be determined from a regression in the whole of Iran. This 4-parameter model should absorb possible GPS-coordinates errors relative to a geocentric system, and at the same time should absorb long-wavelength geoid errors. The datum shift parameters derived from the regression are therefore not to be used for any kind of coordinates transformation. After performing the regression and applying equ. (13) the results improve slightly, the σ N (FFT) reduces from 1.56 to 1.27 m for baselines of all five selected profiles It is noted that the corresponding datum scale and shift parameters (a1 to a4) are respectively equal to 5.20, 4.13, 15.19 and 5.25 m, and are unrealistic in the case of a true scale and datum shift, but seem useful for absorbing the long-wavelength geoid error. (table 3)

CONCLUSIONS AND RECOMMENDATIONS

This research attempted to test the accuracy of the Iranian gravimetric geoid using GPS and leveling data. According to the results of this research the mean absolute accuracy of the IfAG computed geoid is estimated to be 1.56 m. Similarly for five selected profiles I get accuracy's within the range of 0.90 to 1.92 m. The best accuracy's is encountered in the west and center of the country (0.90 and 0.91 m, respectively) and the least in the north and south-east (1.92 and 1.27 m, respectively). From the distribution of gravity points in Iran it can be seen that accuracy is related directly to the density of gravity points. Meanwhile these areas have also rough topography, in addition to the leak of gravity data it is possible that there are some problems in the DTM, specially with the heights derived from 1:250000 maps. The tests of the relative accuracy indicate an accuracy of 35.75 ppm for all traverses baselines and 21.32 - 57.66 ppm for the five selected profiles. Again I the worst results are encountered in the north and southeast of the country (35.23 and 57.66 ppm).

For testing the internal estimates of accuracy of the IfAG gravimetric geoid the author could not get any precise internal estimates from the IfAG group, but according to the estimates of a member of the IfAG group the standard deviation of their solutions can be probably is more than a meter [14]. Hence, the research obtained external estimates of 1.56 m appears to be realistic. Referring to results of section 3, the fit of the IfAG geoid (for the whole of the country) with respect to GPS/leveling values is better than that of OSU91A solution. Until another improvement of the current geoid, the IfAG solution should be used in surveying and geodesy projects.

In order to get a more precise geoid, says a geoid with a 1-ppm accuracy for short bases and 10 ppm for long bases and in rough topography (such as Alborz or Zagros Mountains) it is necessary to use more gravity data. It is noted that a comparison of gravity data coverage of Iran with Turkey or Germany shows that they have a greater density of gravity observation, some 2-5 km [11] also for the computation of a precise geoid it is necessary to have 50*50 m grid of DTM. It is clear that the interpolation of height data from 1:250000 maps do not give appropriate accuracy for the geoid. For example, Turkey used 1:25000 maps for the interpolation of DTM data. [12]. In the following, the main recommendations for further work are given.

1- for any future tests it is recommended to use better density and distribution of GPS/leveling points.

2- the quality of GPS and leveling information in testing the geoid is important in the future; results of the new adjustment of leveling network with heights corrected for gravity and other systematic errors and 2 frequency-GPS receivers with proper data analysis should be used.

3- Until new gravimetric geoid becomes available it is recommended that using the current geoid in general GPS/leveling projects could be limited only to short distances (say, less than 10 km) and only for height differences (in a relative form). For example GPS/leveling method can be employed in photogrammetric ground control for producing current 1:25000 map of the country [13].

4- The IfAG geoid should be further tested against the other external data estimator such as astro-geodetic deflections or satellite altimetery in Caspian and Oman Sea.

5- it is noted that estimating any better geoid with current data is impossible so it is really necessary to improve density of gravity points and their DTM data accuracy's.

6- for determination of any precise geoid also it is necessary to using newer techniques such as the Stokes-Helmert approach [13].

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Table (2a). Sratistical analysis of the relative accuracy of the five GPS/Leveling profiles (m.).

PROFILE	STATSTIC	$\sigma\Delta N(GPS)$	$\sigma\delta\Delta N$
NO. 1 WEST	RMS	2.05	2.24
	PPM	$\sigma\Delta N(FFT)/D =$	26.5
NO. 2 NORTH	RMS	2.30	2.60
	PPM	$\sigma\Delta N(FFT)/D =$	35.23
NO. 3 CENTER	RMS	2.06	2.37
	PPM	$\sigma\Delta N(FFT)/D =$	21.32
NO. 4 EAST	RMS	2.09	2.19
	PPM	$\sigma\Delta N(FFT)/D =$	28.29
NO. 5 SOTH-EAST	RMS	3.65	4.14
	PPM	$\sigma\Delta N(FFT)/D =$	57.66
ALL OF FIVE PROFILES	RMS	2.70	1.07
	PPM	$\sigma\Delta N(FFT)/D =$	35.75

Table (2b). Relative geoid information of five GPS/Leveling profiles (m.).

PROFILE	FROM	TO	DIST.	δN			$\delta\Delta$ N	$\delta\Delta$ N
				OSU	GPS	FFT	FF-OSU	FFT-GPS
NO. 1 WEST	150	172	75799.752	3.19	2.96	3.94	0.75	0.98
	172	14	115468.25	-1.98	-1.24	-1.92	0.06	-0.68
	14	148	83342.661	20.05	0.32	1.56	-0.49	0.74
	148	236	75794.119	2.32	3.22	2.40	-0.42	-0.81
	236	196	82796.101	-0.29	-0.73	0.33	0.62	1.06
NO. 2 NORTH	13	107	70087.121	2.59	1.61	0.15	-2.44	-1.46
	107	191	82520.000	-1.55	-4.36	-4.68	-3.13	0.18
	191	190	105683.22	-4.45	0.30	0.68	5.13	-0.12
	190	174	80522.991	-2.80	-3.46	-5.54	-2.74	-2.08
	174	9	78508.409	-2.16	-2.35	-3.78	-1.62	-1.43
	9	211	52197.933	-1.97	-3.34	-1.61	0.36	1.73
	211	80	68455.972	-2.28	-0.06	-0.74	1.54	-0.68
	80	100	58910.232	-2.07	-0.70	-1.94	0.13	-1.24
NO. 3 CENTER	158	15	105675.21	-2.91	-3.34	-2.09	0.82	1.25
	15	66	97701.555	0.36	1.70	0.33	-0.53	-1.37
	66	2	109820.95	0.98	-0.68	-0.00	-0.98	0.68
	2	50	79103.297	-2.07	-0.33	-1.14	0.93	-0.31
NO. 4 EAST	57	150	97426.739	3.58	2.30	3.14	-0.44	0.84
	160	59	79393.579	-1.15	-2.50	-3.19	-2.04	-0.59
	59	200	73695.239	-1.08	-1.36	-0.95	0.13	0.41
	200	171	100525.08	-2.96	-2.11	-1.01	1.95	1.10
	171	154	70673.079	-3.12	-1.8	-1.34	1.75	0.46
	154	197	59336.705	1.95	1.68	1.32	-0.63	-0.36
N0. 5 SOUTH-EAST	123	32	58381.593	0.50	1.53	2.75	2.25	1.10
	32	187	77031.760	1.70	-1.03	-1.11	-2.81	-0.08
	187	220	84700.258	0.00	0.79	0.15	0.15	-0.64
	220	228	89223.529	-2.57	-1.18	-.96	1.61	0.22
	228	44	56935.584	-3.07	-1.71	-3.55	-0.48	-1.84
	44	101	71088.915	-6.48	-8.31	-5.08	1.40	3.23
	101	130	76064.332	-3.65	-6.24	-8.99	-5.34	-2.75

Table (3). Improving of geoid using regression model.

PROFILES	BEFORE	AFTER
	$\sigma N(FFT)$	$\sigma N(FFT)$
NO. 1 (WEST)	0.90	0.79
NO. 2 (NORTH)	2.05	0.98
NO. 3 (CENTER)	1.17	0.78
NO. 4 (EAST)	1.35	0.82
NO. 5 (SOUTH-EAST)	1.46	1.25
ALL OF 5 PROFILES	1.56	1.27