CAN THE NEW DEVELOPED EARTH GRAVITATIONAL MODEL 2008 BE USED AS A GEOIDAL MODEL FOR KUWAIT?

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ABSTRACT

The present work focuses on the evaluation of the new Earth Gravitational Model (EGM2008) that was recently released by the NGA (National Geospatial-Intelligence Agency, U.S)/EGM-development team. The Earth Gravitational Model (EGM2008) is the highest resolution model up to degree 2160 which has been developed and published. EGM2008 incorporates improved 5x5 minutes gravity anomalies and has benefited from the latest GRACE based satellite solutions.

This paper presents an overview of the evaluation results for the new Earth Gravitational Model EGM2008 by using GPS and leveled elevations, orthometric heights, over four test areas in Kuwait. The main goal of this research is to find answers to the following question: is EGM2008 the best available Geoidal Model for Kuwait? The results of EGM08 application over the three tested areas confirmed that EGM08, without any doubt, makes good contribution to the geodetic vertical control.

1. INTRODUCTION

In Kuwait, the vertical datum can be classified into two main categories. The first category of elevation systems is assigned to the on-shore projects and the second is related to the off-shore. According to the nature of the projects, the first category can be divided into two main sectors. The first sector is related to the oil industries applications, namely Mina Ahmadi Chart Datum "MACD" and the second one is for non-oil industries, utilities, applications, namely Public Work Department "PWD" vertical datum. The main institurations that are still use the MACD is the Kuwait Oil Company "KOC" and the Kuwait National Petroleum Co. "KNPC". KOC Engineering currently bases all elevations on the internal elevation datum MACD. Most of KOC' drawings and documents have quoted this datum for all oil-fields.

Kuwait Municipality (KUDAMS) established a series of Bench Marks through the domestic areas of Kuwait Governorates. This Bench Marks have been assigned 1st order accuracy. MoD has a series of Bench Marks "BM" chains through out Kuwait. These chains of BM's have been assigned as 2nd order accuracy by Kuwait Municipality. Both types are referred to the PWD vertical datum. Figure (1) depicts the chains of Bench Marks that utilize PWD as a vertical datum. On the other side, KOC established a series of Bench Marks along Burgan, Managish & North of Kuwait. These chains of BM's have been assigned as 2nd order accuracy by check.

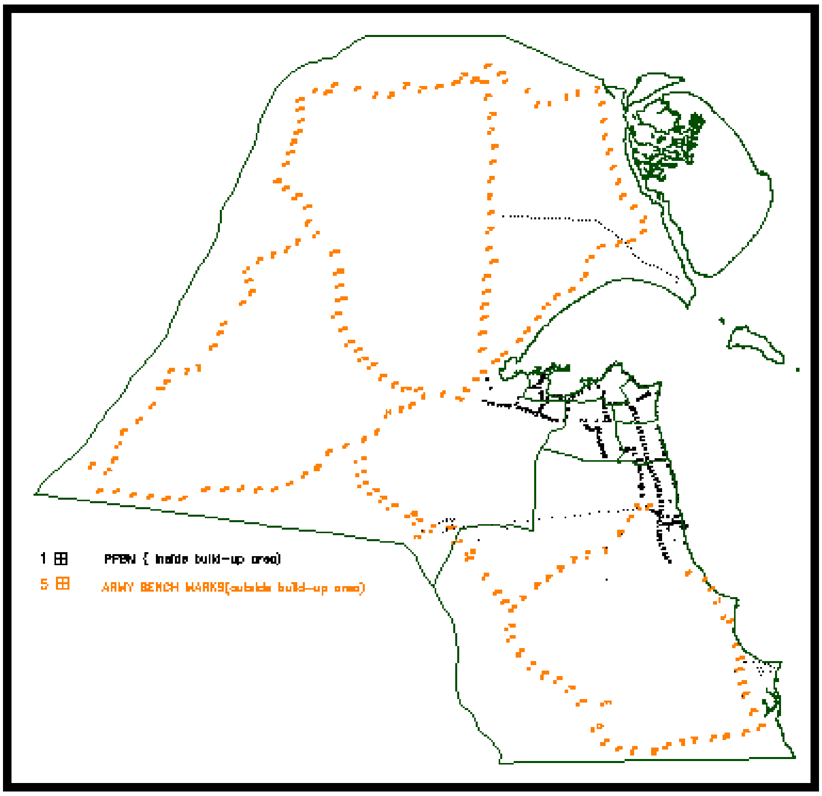


Figure (1): shows the distribution of Kuwait Municipality & MoD Bench Marks

There are quoted separation values between MACD and other elevation datums used within KOC and used by MoD & Municipality. On the other hand, the Kuwait Municipality, Ministry of Defense "MoD", Ministry of Public Works "MPW", the Ministry of Electricity, Water "MEW" and all governmental, non-oil industries, authorities are considered the main authorities which use the PWD vertical datum. Figure (2), shows the adopted separation as listed by KOC and Kuwait Municipality (KUDAMS). The greatest values of information in this sketch is the separation value between MACD & PWD and the confirmation one can get that the Kuwait Local Chart Datum "KLCD" used for off-shore project is coincident with PWD On-shore. Additionally, the separation between the Mean Sea Level, newly established by KUDAMS in 1980's, and the PWD is about 1.606m.

One of the most fundamental concepts in geodesy is the ***geoid,*** which is defined as an equipotential surface that coincides with the mean sea level (MSL) and extends below continents. The geoid surface is much smoother than the natural Earth surface despite of its global undulations (changes). It is very close to an ellipsoid of revolution, but more irregular. Hence it is well approximated by the ellipsoid. Historically, the geoid has served as reference surface for geodetic levelling. The geoid height or geoidal undulation *(N)* is described by the separation of the geoid from the ellipsoid of revolution. Due to the irregularity of the geoid, it cannot be described by a simple mathematical function.

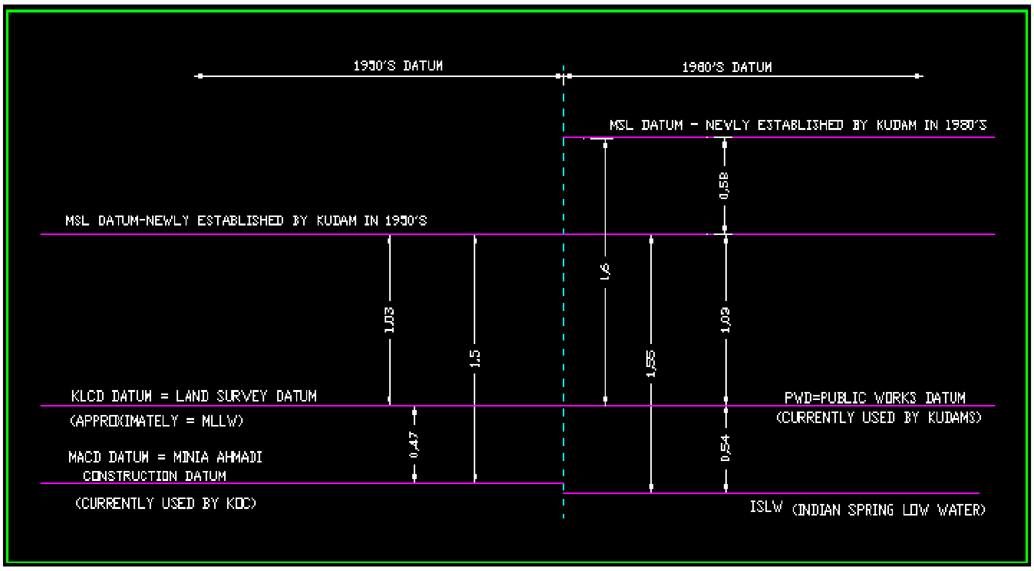


Figure (2): The Elevation datums of Kuwait

Unfortunately, Kuwait has neither geoidal model nor any gravity data measured across its land. Additionally, no institution in Kuwait pay attention to the ellipsoidal heights, where all the available control points are defined in two systems, namely 2-D for horizontal geodetic control works and 1-D for vertical control, namely elevations. Normally GPS works are based upon assuming that the ellipsoid is tangeting the Geoid at the initial control point, this means that the ellipsoidal height equals the orthometric height at the used control point, then a chain of leveling works will be done across all the areas of interest. The final results are chains of three coordinate's points where the first 2-D refers to the horizontal system and the last one refers to the elevation.

2. THE EGM2008 GLOBAL GRAVITATIONAL MODEL

The recent release of the new Earth Gravitational Model EGM2008 by the US national Geospatial-Intelligence Agency (Pavlis et al. 2008) is undoubtedly a major breakthrough in global gravity field mapping. For the first time, a Spherical Harmonic "SH" model complete to degree 2190 and order 2159, is available for the Earth's external gravitational potential, for the used data sources see figure (3). Full access to the model's coefficients and other processing programs is available from the NGA site at: http://earthinfo.nima.mil/GandG/wgs84/gravitymod/index.html.

The EGM08 leads to an unprecedented level of spatial sampling resolution (~ 9 Km) for the recovery of gravity field functional contributes in a most successful way to the continuing efforts of geodetic community during the last years (and after the launch of the satellite missions CHAMP and GRACE) for a high-resolution and high accuracy reference model of Earth's static (mean) gravity field. Furthermore, it provides an indispensable tool to support new gravity field studies and other Earth monitoring projects and the ongoing development of Global Geodetic Observing System (GGOS) (Pavlis et al. 2008).

Following the official release of the EGM08 model, there is an expected strong interest among geodesists to quantify its actual accuracy with several validation techniques and external data sets, independently of the estimation and error calibration procedures that were used for its development. It is worthwhile to mention that The EGM2008 does not include any GPS/Levelling or astronomic deflection of the vertical data. Remarkable improvements have been obtained when EGM2008 has been compared against GPS/levelling in USA, where the weighted standard deviation has been decreased from 18.2 cm (for the EGM96) to 4.8 cm in case of removing a linear trend (Pavlis et al. 2008), see figure (4).

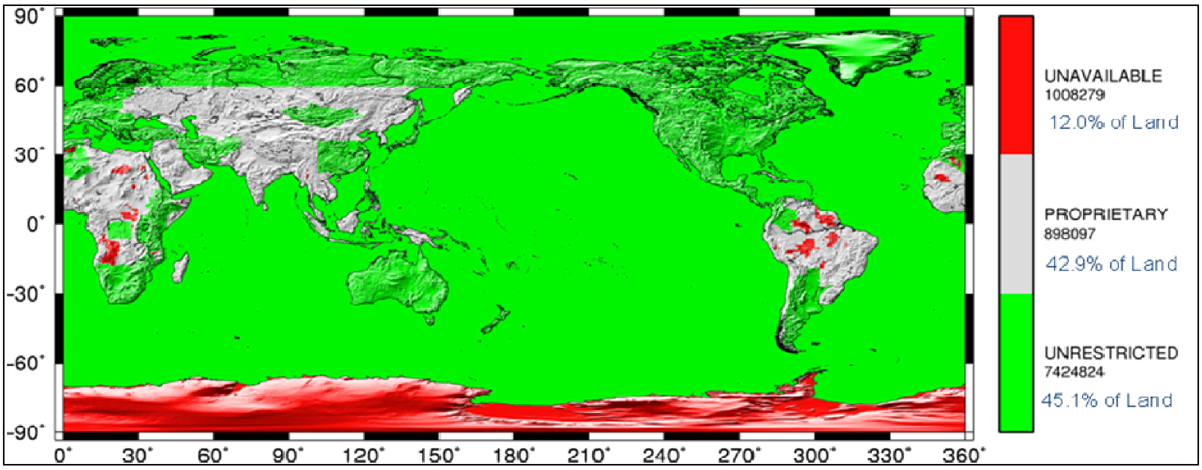


Figure (3): 5′×5′ Δg Data Availability {Source K.Pavlis et al. 2008}

In response to the above interest and as part of the related activities that have been coordinated by the IAG/IGFS Joint Working Group on the Evaluation of Global Earth Gravity Models, the objective of this paper is to present the results of EGM08 validation tests that were performed along the Kuwaitian's territory.

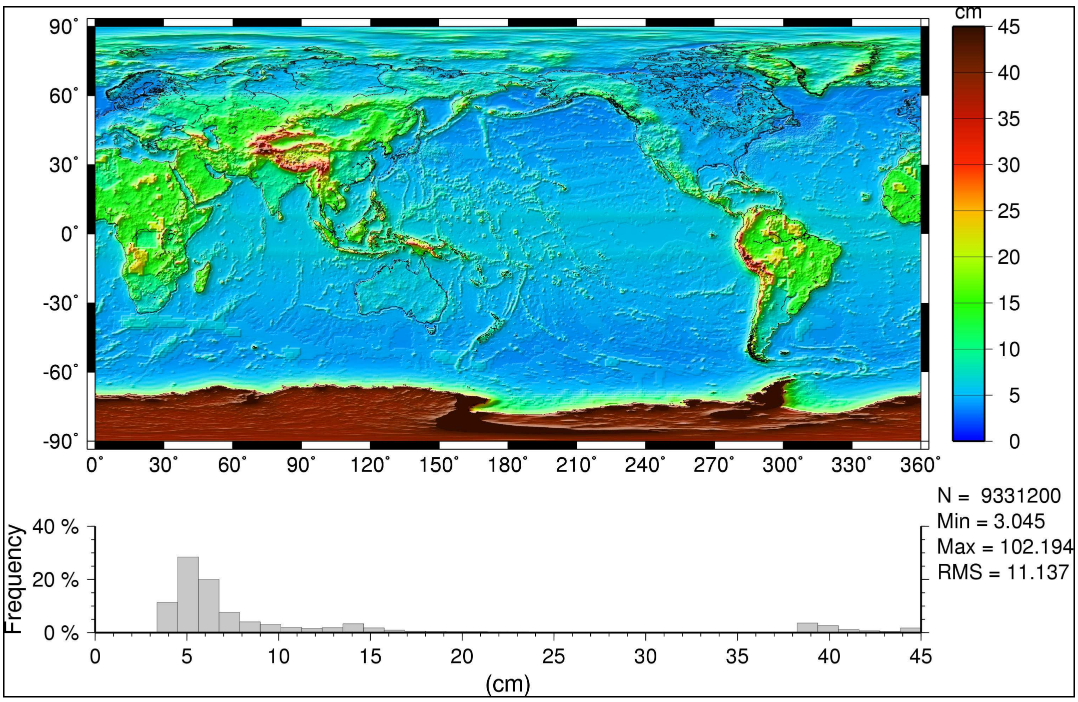


Figure (4): 5′×5′ Geoidal Undulation "N" Commission error {Source Pavlis et al. 2008}

3. THE RELATION BETWEEN THE GEOID AND ELLIPSOID

The geoid is considered as the true surface of the earth in surveying, where all surveying quantities are observed relative to its surface. This is definitely because the vertical axis of any surveying instrument is adjusted towards to the gravity vertical, or by other words, perpendicular to its surface at the occupied point. On the other hand, the surveying computations should be performed relative to a mathematical surface, which is chosen as one of three different surfaces as mentioned above. If we consider the ellipsoid as an example herein, we can visualize the relation between the computational and the true surfaces of the earth in figure (5). High-resolution geoid models are valuable to geodesy, surveying, geophysics and several geosciences, because they represent the datums to height differences and gravity potential. Moreover, they are important for connection between local datums and the global datum, for purposes of positioning, levelling, inertial navigation system and geodynamics.

The impact of wide and rapid use of the Global Navigation Satellite System (GNSS) has revolutionized the fields of surveying, mapping, navigation, and Geographic Information Systems (GIS) and replaced the traditional time-consuming approaches. In particular, GPS offers a capability of making geodetic measurements with a significant accuracy that, previously, required ideal circumstances, weather and other special preparations. Further, the new accuracy is achieved efficiently and economically than was possible before GPS. The GPS is 3-D; this implies that it supplies heights as well as horizontal positions. The given height in this system is computed relative to the ellipsoid; hence, it is called *ellipsoidal height*. However, height from spirit levelling is related to the gravity field of the Earth, it is called *orthometric height*. The geoid height is the difference between the ellipsoidal and the *orthometric height*. It is well known that the *orthometric height* can be obtained without levelling by using the *ellipsoidal* and *geoidal height* according to the following relation: $\boldsymbol{h = H + N}$

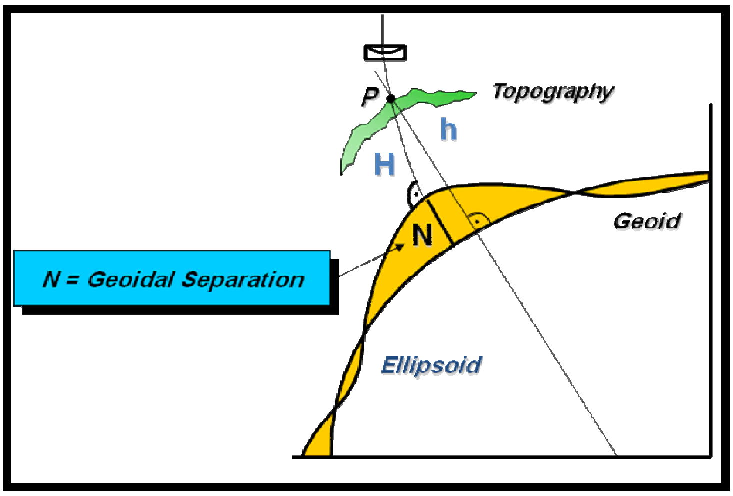


Figure (5): The relation between ellipsoid height & Elevation

Figure (5) illustrates *h*, namely the geodetic height, which is defined as the distance from the point to the ellipsoid surface measured on the ellipsoid normal (the perpendicular line to the ellipsoid at that point). *H* is the orthometric height, which is defined as the distance from the point to the geoid surface measured on the gravity vertical (the perpendicular line to the geoid at that point). θ is the angle between the gravity vertical and the ellipsoid normal. ***N*** is the geodetic undulation, which is the difference between the geodetic height and the orthometric height. The obtained *orthometric height* must be determined with high accuracy. Therefore, the determination of a high-resolution geoid has become a matter of great importance to cope possibly with accuracy level of height from GPS. Hence, it is possible to say that gravimetric geoid models offer the third dimension to GPS.

In order to convert GPS-derived ellipsoidal heights to orthometric heights we need an accurate model of geoidal heights. This is where the difficulty arises – it is extremely difficult to determine such a model, or at least to determine an accurate model especially in an area like Kuwait where there is no available gravity data and/or harmonized three Dimensional control points. Thus the official release of the EGM08 model motivated us to quantify its actual accuracy with available leveling data tests measured across several areas in Kuwait. This motivation was enhanced with confirming that a gravitational data was measured covering Kuwait territory and surrounding areas as well as the 5′×5′ Geoidal Undulation "N" Commission error, where it was confirmed that the error Kuwait land with an N error of 10-15 cm, see figures (3) and (4) (Pavlis et al. 2008).

4. VERIFICATION OF THE USING EGM08 ACROSS KUWAITIAN TERRITORY

To study the impact of EGM08 on vertical control works in Kuwait, three tests were performed, see figure (6). The first test area was located at mid of Kuwait, BurKan. It was chains of leveling loops that were done along a line of about 62 km in the mid of Kuwait. The second tested area was a line covering the upper northern half of Kuwait with length about 140km. The last test was also chains of leveling loops that were conducted along line of 47 km in the north of Kuwait.

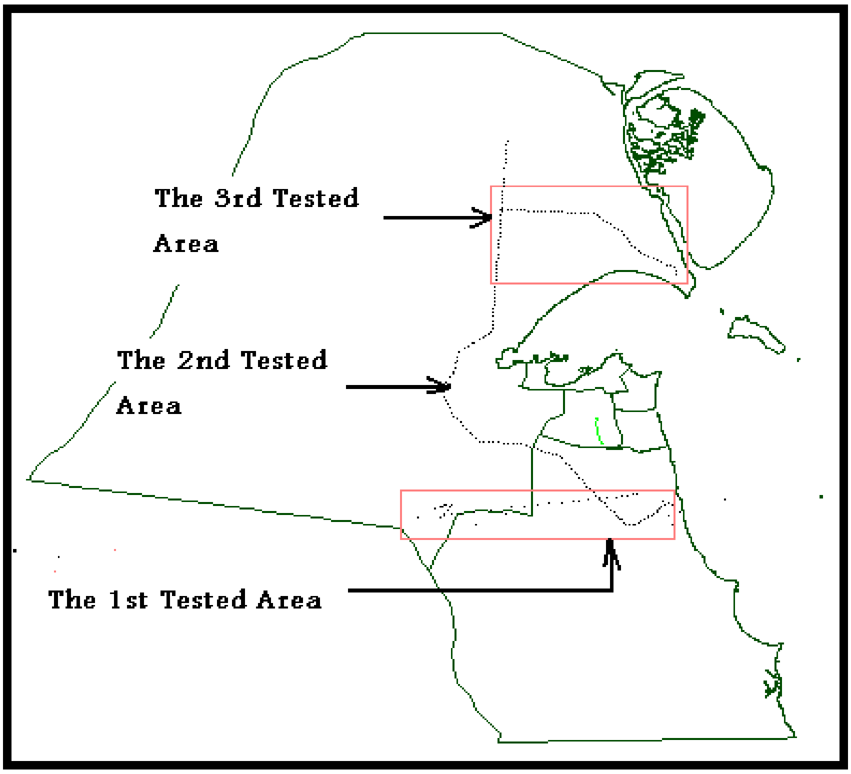


Figure (6): The main layout of the tested areas

Keep in mind that because of the available official control points are given as 3-D coordinate's points where the first 2-D refers to the horizontal system and the last one refers to the elevation, no attention were paid to GPS ellipsoidal height. So, to reduce the computation load burden, GPS works are normally based upon assumption that the ellipsoid is tangeting the geoid at one of the official given control points. This means that the ellipsoidal height equals the given elevation, orthometric height, at the chosen control point. This means that a negative value of the Geoidal Undulation *N* was added at that point to make the above assumption work:

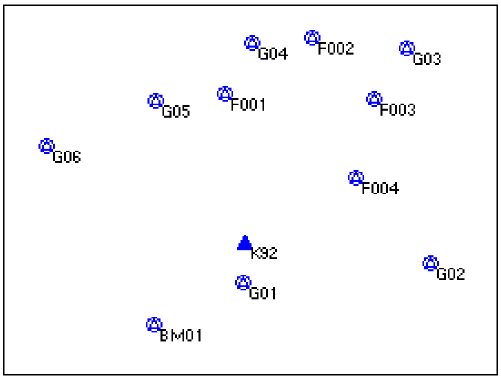
$$h - H = 0 = N - N$$

Then chains of leveling loops works are done conducting all the new established control points along the areas of interest. To see how the EGM08 is useful for Kuwait, figure (7) depicts the geometric configuration of the first tested area at mid of Kuwait. A GPS network and closed leveling loops was covered a line with length about 62 km, oriented west north-west, as seen in figure (7), for displaying purpose, the line's points were rotated clockwise by 90^o the whole area. Point K92 was considered as a base for horizontal and vertical for the whole tested areas after connecting it to the nearest Bench Mark by leveling loops. The resulted WGS84 Latitude and Longitude of all points were used in the EGM08 to compute the geoidal undulation ***N***.

Table (1) outlined the output EGM08 undulation***s*** for the line's points. The change of observed ***N***, namely ***DeltaN1***, was computed for every point, by utilizing the resulted ellipsoidal height ***h*** and the elevation resulted by leveling ***H***, by: ***DeltaN1 = h – H.*** Keep in mind that ***DeltaN1*** is taken to equal zero at the reference point and all the other points were shifted with this value. On the other hand, the change of geoidal undulation resulted from EGM08, namely ***DeltaN2***, was computed for each point by: ***DeltaN2*** = $N_{EGM08} - N_{EGM\ at\ base}$ where N_{EGM08} refers to the computed N_{EGM08} by the EGM2008 model, $N_{EGM\ at\ base}$ refers to the computed EGM08 ***N*** value computed for the N_{K92} base point. As it is shown table (1), the absolute differences bet. ***DeltaN1*** and ***DeltaN2*** are ranged between 9.88 cm and 3.7 mm. These differences confirm the results that were obtained by Pavlis et al. (2008) around different regions in the globe.

Table (1): The differences between the observed and the EGM08 geoidal undulation change for the first tested area

Pt. Id	DeltaN1 = h - H	N (EGM08)	DeltaN2 (EGM08)	DeltaN1-DeltaN2
BM01	0.0269	-13.312	0.041	-0.0141
F001	0.0161	-13.351	0.002	0.0141
F002	-0.0144	-13.389	-0.036	0.0216
F003	-0.0453	-13.411	-0.058	0.0127
F004	-0.0443	-13.401	-0.048	0.0037
G01	-0.0064	-13.351	0.002	-0.0084
G02	-0.0811	-13.427	-0.074	-0.0071
G03	-0.054	-13.427	-0.074	0.02
G04	0.0095	-13.365	-0.012	0.0215
G05	0.0444	-13.323	0.03	0.0144



Zooming the western part

G06	0.0841	-13.277	0.076	0.0081
H01	-1.7306	-14.993	-1.64	-0.0906
H02	-1.6801	-14.939	-1.586	-0.0941
H03	-1.6389	-14.894	-1.541	-0.0979
H04	-1.5788	-14.833	-1.48	-0.0988
H05	-1.5008	-14.755	-1.402	-0.0988
H06	-1.4175	-14.676	-1.323	-0.0945
H07	-1.3268	-14.587	-1.234	-0.0928
H08	-1.2365	-14.5	-1.147	-0.0895
K74	0.223	-13.112	0.241	-0.018
K93	-0.3241	-13.634	-0.281	-0.0431
K94	-0.5762	-13.896	-0.543	-0.0332
P01	-0.1684	-13.516	-0.163	-0.0054
P02	-0.2829	-13.629	-0.276	-0.0069
P03	-0.4296	-13.77	-0.417	-0.0126
P04	-0.548	-13.874	-0.521	-0.027
P05	-0.6295	-13.958	-0.605	-0.0245
P06	-0.744	-14.059	-0.706	-0.038
P07	-0.8582	-14.158	-0.805	-0.0532
P08	-0.9735	-14.26	-0.907	-0.0665
P09	-1.0912	-14.365	-1.012	-0.0792
P10	-1.1808	-14.45	-1.097	-0.0838
PL245	-2.0258	-15.324	-1.971	-0.0548
PL257	-1.7619	-15.026	-1.673	-0.0889
PL85	-1.7418	-15.05	-1.697	-0.0448
K92	0	-13.353	0	0
PEL248	-2.1509	-15.5	-2.147	-0.0039

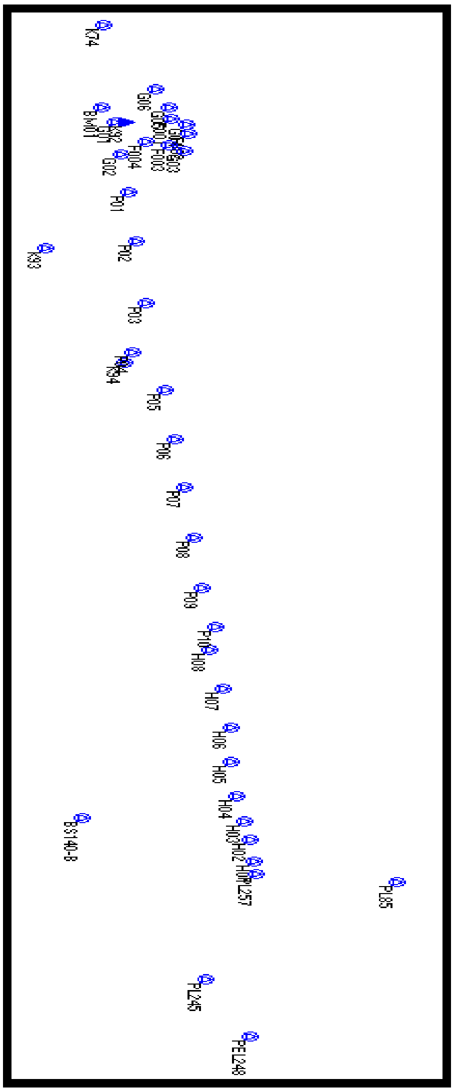
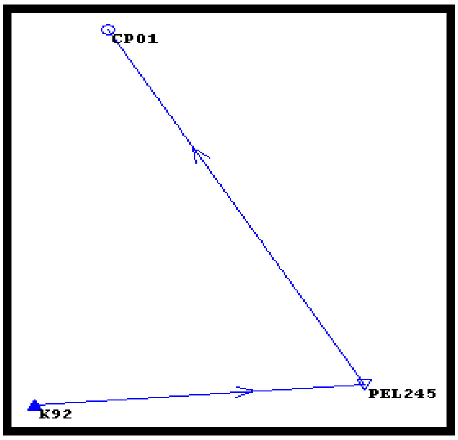


Figure (7): The Layout of the first area (90° rotated)

The second tested area was a GPS network covered a line of closed leveling loops with length exceed 140 km, as seen in figure (9). Keep in mind that the ellipsoidal heights for all the three tested areas were computed relative to K92 as a base station see figure (8), to enable us fixing the value of geoidal undulation $\boldsymbol{N}_{K92}$ at K92.



Pt. Id	Sol. Type	Ell. Hgt	Qty
CP01	Measured	62.156	0.0001
PEL245	Measured	48.765	0.0002
K92	Control	189.848	0

Figure (8): The relation between the three tested areas

As it is presented in table (2), the differences between the computed ***DeltaN1*** and the model ***DeltaN2*** values are ranged between -0.06 cm and +0.078cm. In spite of we still deploy K92 as a base for the second tested area; it is still showing accurate values for the model undulation values. It is worthwhile to mention that the vertical datum for both areas was "MACD" vertical datum.

Table (2): The differences between the observed and the EGM08 geoidal undulation change for the second tested area

Pt. Id	DeltaN1 (h-H)	N (EGM08)	DeltaN2 (EGM2008)	DeltaN1-DeltaN2
PL245	-1.950	-15.324	-1.971	0.021
V01	-1.943	-15.346	-1.993	0.05
V02	-1.894	-15.31	-1.957	0.063
V201	-1.882	-15.297	-1.944	0.062
V202	-1.868	-15.284	-1.931	0.063
V03	-1.877	-15.283	-1.93	0.053
V04	-1.862	-15.265	-1.912	0.05
V401	-1.841	-15.262	-1.909	0.068
V402	-1.834	-15.255	-1.902	0.068
V05	-1.829	-15.221	-1.868	0.039
V06	-1.773	-15.196	-1.843	0.07
V07	-1.756	-15.156	-1.803	0.047
V08	-1.714	-15.144	-1.791	0.077
V09	-1.684	-15.11	-1.757	0.073
V10	-1.662	-15.072	-1.719	0.057
V11	-1.65	-15.041	-1.688	0.038
V12	-1.656	-15.006	-1.653	-0.003
V13	-1.632	-14.987	-1.634	0.002
V14	-1.589	-14.95	-1.597	0.008
V15	-1.556	-14.911	-1.558	0.002
V16	-1.517	-14.893	-1.54	0.023
V17	-1.506	-14.873	-1.52	0.014
V18	-1.491	-14.862	-1.509	0.018
V19	-1.493	-14.844	-1.491	-0.002
V20	-1.471	-14.832	-1.479	0.008
V21	-1.39	-14.807	-1.454	0.064
V22	-1.376	-14.776	-1.423	0.047
V23	-1.354	-14.754	-1.401	0.047
V24	-1.355	-14.725	-1.372	0.017
V25	-1.328	-14.702	-1.349	0.021
V26	-1.292	-14.684	-1.331	0.039
V27	-1.285	-14.651	-1.298	0.013
V28	-1.275	-14.629	-1.276	0.001
V29	-1.242	-14.603	-1.25	0.008
V30	-1.217	-14.579	-1.226	0.009
V31	-1.204	-14.56	-1.207	0.003
V32	-1.106	-14.537	-1.184	0.078
V33	-1.106	-14.519	-1.166	0.06

V34	-1.066	-14.497	-1.144	0.078
V35	-1.068	-14.477	-1.124	0.056
V36	-1.077	-14.455	-1.102	0.025
V37	-1.073	-14.434	-1.081	0.008
V38	-1.072	-14.413	-1.06	-0.012
V39	-1.043	-14.393	-1.04	-0.003
V40	-1.013	-14.375	-1.022	0.009
V41	-0.991	-14.341	-0.988	-0.003
V42	-0.995	-14.325	-0.972	-0.023
V43	-0.963	-14.294	-0.941	-0.022
V44	-0.904	-14.263	-0.91	0.006
V45	-0.906	-14.233	-0.88	-0.026
V46	-0.853	-14.204	-0.851	-0.002
V47	-0.838	-14.176	-0.823	-0.015
V48	-0.812	-14.152	-0.799	-0.013
V49	-0.788	-14.121	-0.768	-0.02
V50	-0.748	-14.089	-0.736	-0.012
V51	-0.723	-14.061	-0.708	-0.015
V52	-0.697	-14.028	-0.675	-0.022
V53	-0.653	-13.994	-0.641	-0.012
V54	-0.623	-13.953	-0.6	-0.023
V55	-0.571	-13.919	-0.566	-0.005
V56	-0.528	-13.871	-0.518	-0.01
V57	-0.511	-13.834	-0.481	-0.03
V58	-0.405	-13.793	-0.44	0.035
V59	-0.398	-13.759	-0.406	0.008
V60	-0.431	-13.734	-0.381	-0.05
V61	-0.389	-13.72	-0.367	-0.022
V62	-0.409	-13.699	-0.346	-0.063
V63	-0.36	-13.68	-0.327	-0.033
V64	-0.298	-13.659	-0.306	0.008
V65	-0.309	-13.64	-0.287	-0.022
V66	-0.294	-13.616	-0.263	-0.031
V67	-0.262	-13.597	-0.244	-0.018
V68	-0.252	-13.583	-0.23	-0.022
V69	-0.215	-13.574	-0.221	0.006
V70	-0.203	-13.568	-0.215	0.012
V71	-0.219	-13.559	-0.206	-0.013
V72	-0.218	-13.553	-0.2	-0.018
V73	-0.229	-13.56	-0.207	-0.022
V74	-0.226	-13.567	-0.214	-0.012
V75	-0.248	-13.576	-0.223	-0.025
V76	-0.235	-13.587	-0.234	-0.001
V77	-0.277	-13.629	-0.276	-0.001
V78	-0.33	-13.666	-0.313	-0.017
V79	-0.345	-13.678	-0.325	-0.02
V80	-0.344	-13.689	-0.336	-0.008

V81	-0.39	-13.707	-0.354	-0.036
V82	-0.364	-13.714	-0.361	-0.003
V83	-0.392	-13.73	-0.377	-0.015
V84	-0.4	-13.749	-0.396	-0.004
V85	-0.476	-13.794	-0.441	-0.035
V86	-0.503	-13.837	-0.484	-0.019
V87	-0.527	-13.867	-0.514	-0.013
V88	-0.548	-13.884	-0.531	-0.017
V89	-0.566	-13.918	-0.565	-0.001
V90	-0.602	-13.949	-0.596	-0.006
V91	-0.66	-13.975	-0.622	-0.038
V92	-0.656	-14.004	-0.651	-0.005
V93	-0.666	-14.017	-0.664	-0.002
V94	-0.702	-14.024	-0.671	-0.031
V95	-0.683	-14.028	-0.675	-0.008
V96	-0.699	-14.032	-0.679	-0.02
V97	-0.698	-14.035	-0.682	-0.016
V98	-0.701	-14.04	-0.687	-0.014
V99	-0.713	-14.045	-0.692	-0.021
V100	-0.707	-14.05	-0.697	-0.01
V101	-0.711	-14.057	-0.704	-0.007
V102	-0.7	-14.061	-0.708	0.008
V103	-0.706	-14.067	-0.714	0.008
V104	-0.725	-14.075	-0.722	-0.003
V105	-0.737	-14.083	-0.73	-0.007
V106	-0.728	-14.095	-0.742	0.014
V107	-0.74	-14.107	-0.754	0.014
V108	-0.759	-14.117	-0.764	0.005
V109	-0.743	-14.126	-0.773	0.03
V110	-0.832	-14.138	-0.785	-0.047
V111	-0.795	-14.147	-0.794	-0.001
V112	-0.815	-14.157	-0.804	-0.011
V113	-0.825	-14.167	-0.814	-0.011
V114	-0.84	-14.186	-0.833	-0.007
V115	-0.807	-14.198	-0.845	0.038
V116	-0.899	-14.212	-0.859	-0.04
V117	-0.877	-14.226	-0.873	-0.004
V118	-0.883	-14.24	-0.887	0.004
V119	-0.9	-14.259	-0.906	0.006
V120	-0.913	-14.274	-0.921	0.008
V121	-0.926	-14.286	-0.933	0.007
V122	-0.946	-14.302	-0.949	0.003
V123	-0.937	-14.321	-0.968	0.031
V124	-0.953	-14.328	-0.975	0.022
V125	-0.952	-14.339	-0.986	0.034
V126	-0.988	-14.357	-1.004	0.016
V127	-0.999	-14.374	-1.021	0.022

V128	-1.017	-14.39	-1.037	0.02
V129	-1.05	-14.407	-1.054	0.004
V130	-1.064	-14.424	-1.071	0.007
V131	-1.084	-14.439	-1.086	0.002
V132	-1.102	-14.453	-1.1	-0.002

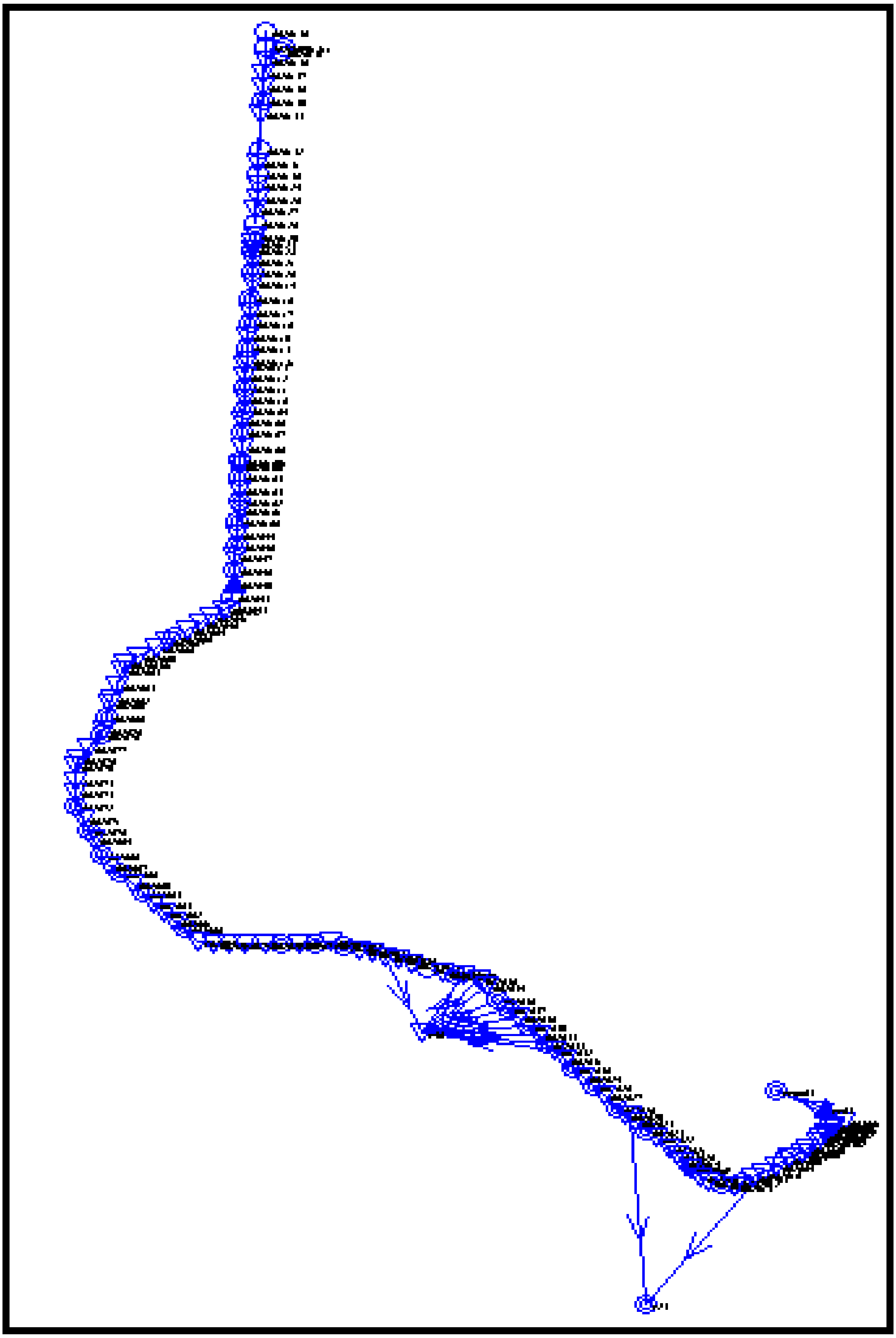


Figure (9): The Layout of the second area

Considering the last tested area, the third area, figure (10) indicates the geometric configuration of chain of 47 points, half of them its consequences orient west – east and the second half orient mainly north – southern east. Keep in mind that the vertical datum of the second tested area was "PWD", so to convert it to the same datum of the two tested areas 0.47m should be added to the computed PWD elevation, as demonstrated in figure (2). Additionally to unify the base station of all the three tested areas to be K92, a 0.47m should be abstracted from the computed ellipsoid height values relative to CP01 to be referenced to K92.

Table (3) outlines the results of the observed geoidal undulation changes ***N***, namely ***DeltaN1*** and the computed EGM08 ***DeltaN2*** considering K92 as a base. As it is indicated in table (4), the differences between ***DeltaN1*** and ***DeltaN2*** are ranged between -0.109 cm and +0.079 cm. These differences confirm also the results that were obtained by Pavlis et al. (2008) around different regions in the globe.

5 CONCLUSION

Based upon the aforementioned results, the following conclusion can easily be drawn:

- The application of EGM08 without any doubt makes contribution to the geodetic vertical control.
- The differences between the observed change of geoidal undulation ***N***, namely ***DeltaN1*** and the computed EGM08 ***DeltaN2*** are ranged between -10.9 to +7.9 cm which is mostly accurate enough for the construction of new pipelines in the tested areas.

6 REFERENCES

Pavlis, N., Holmes, S., Kenyon, S., and Factor, J. (2008). "An Earth Gravitational Model to degree 2160: EGM2008." Presented at *the 2008 General Assembly of the European Geosciences Union*, Vienna, Austria, April 13-18, Available from: http://earthinfo.nima.mil/GandG/wgs84/gravitymod/egm2008/NPavlis&al_EGU2008.ppt

Table (4): The differences between the observed and the EGM08 geoidal undulation change for the third tested area

Pt. Id	*DeltaN1 = h - H*	*N (EGM08)*	*DeltaN2 (EGM08)*	*DeltaN1 - DeltaN2*
CP01	-0.950	-14.323	-0.970	0.020
D01	-0.987	-14.373	-1.020	0.033
D02	-1.024	-14.400	-1.047	0.023
D03	-1.085	-14.427	-1.074	-0.011
D04	-1.112	-14.455	-1.102	-0.010
D05	-1.114	-14.481	-1.128	0.014
D06	-1.116	-14.507	-1.154	0.038

D07	-1.137	-14.532	-1.179	0.042
D08	-1.208	-14.556	-1.203	-0.005
D09	-1.249	-14.581	-1.228	-0.021
D10	-1.283	-14.605	-1.252	-0.031
D11	-1.300	-14.630	-1.277	-0.023
D12	-1.311	-14.654	-1.301	-0.010
D13	-1.289	-14.679	-1.326	0.037
D14	-1.355	-14.704	-1.351	-0.004
D15	-1.402	-14.732	-1.379	-0.023
D16	-1.416	-14.757	-1.404	-0.012
D17	-1.436	-14.785	-1.432	-0.004
D18	-1.407	-14.812	-1.459	0.052
D19	-1.509	-14.839	-1.486	-0.023
D20	-1.562	-14.868	-1.515	-0.047
D21	-1.602	-14.898	-1.545	-0.057
D22	-1.643	-14.915	-1.562	-0.081
D23	-1.620	-14.930	-1.577	-0.043
D24	-1.577	-14.949	-1.596	0.019
D25	-1.674	-14.969	-1.616	-0.058
D26	-1.602	-14.989	-1.636	0.034
D27	-1.699	-15.009	-1.656	-0.043
D28	-1.717	-15.029	-1.676	-0.041
D29	-1.761	-15.051	-1.698	-0.063
D30	-1.775	-15.070	-1.717	-0.058
D31	-1.789	-15.082	-1.729	-0.060
D32	-1.850	-15.094	-1.741	-0.109
D33	-1.812	-15.108	-1.755	-0.057
D34	-1.817	-15.123	-1.770	-0.047
D35	-1.796	-15.145	-1.792	-0.004
D36	-1.869	-15.169	-1.816	-0.053
D37	-1.799	-15.193	-1.840	0.041
D38	-1.811	-15.221	-1.868	0.057
D39	-1.848	-15.251	-1.898	0.050
D40	-1.851	-15.283	-1.930	0.079
D41	-1.970	-15.311	-1.958	-0.012
D42	-2.039	-15.359	-2.006	-0.033
D43	-2.072	-15.391	-2.038	-0.034
D44	-2.126	-15.425	-2.072	-0.054
D45	-2.109	-15.439	-2.086	-0.023
D46	-2.100	-15.437	-2.084	-0.016

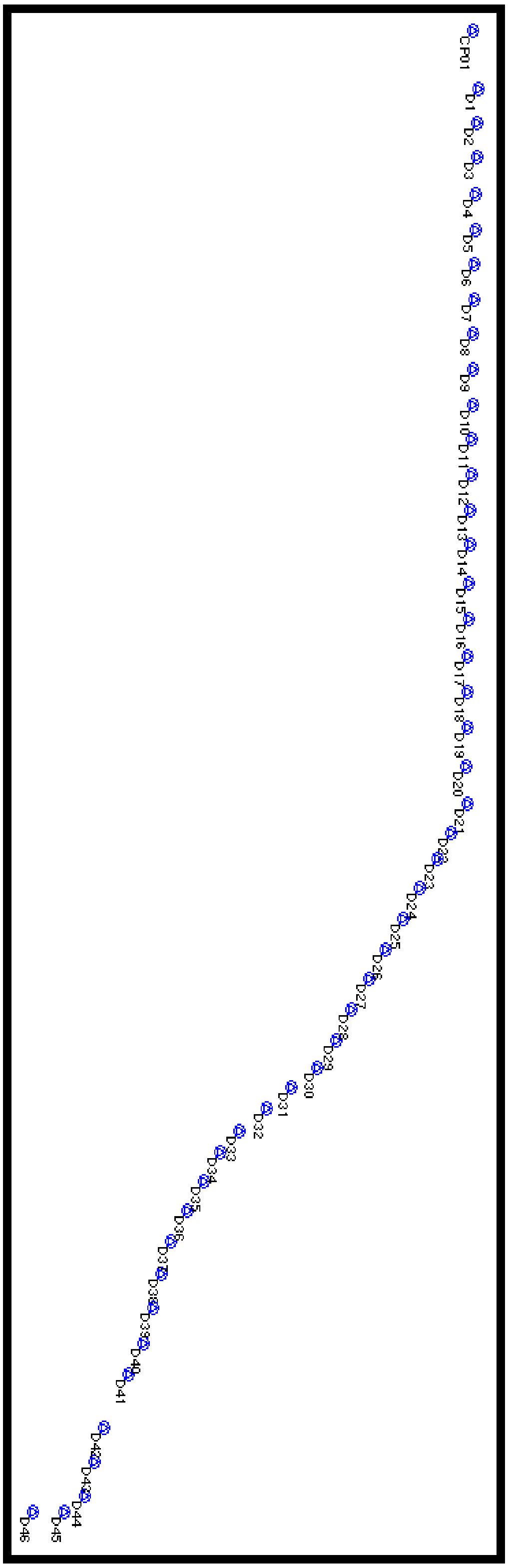


Figure (10): The Layout of the fourth area (90^o rotated)