First Validation of the Hellenic Vertical Datum as a Prerequisite for the Efficient Disaster and Resource Management: The “ELEVATION” Project.

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Key words: Vertical Network evaluation, geoid, GNSS, leveling, Mean Sea Level

SUMMARY

The entity of technical works at national scales is based on well established horizontal and vertical reference networks. The knowledge of the location where an event took place (e.g., natural disaster, crustal deformations and small distortions of a construction) is crucial to crisis management. Additionally, precise knowledge of an incidents’ place is possible to lead to more equitable confrontation from the authorities.

With the applications of modern technology, horizontal position determination is feasible with particularly high precision. With respect to vertical control networks their confrontation is different: the effect of the earth's gravity field, due to the inherent connection of the height information with the natural environment, complicates both the measurement and the utilization of leveling data. The importance of height information is extremely high; it is enough if one thinks of the human activities that dependent on its precise and rigorous determination. The exploitation of surface water resources, as well as underground ones, the construction of large technical infrastructures (dams, bridges), as well as decision-making on environmental issues require, as much as possible, precise and henceforth reliable height information. In combination, therefore, with the horizontal position elevation data complete our knowledge for the three-dimensional location of an incident within the natural environment where we live and act.

In the frame of the action “Archimedes III – Funding of research groups in T.E.I.”, which is co-financed by the E.U. (European Social Fund) and national funds under the Operational Program “Education and Lifelong Learning 2007-2013”, a project for the validation and quality control of the Hellenic vertical network is currently in progress. Two investigation areas, one in Attika and another in Thessaloniki have been chosen. The areas include several height benchmarks of the national trigonometric and leveling networks. Static GPS observations as well as classical spirit leveling in combination with special trigonometric leveling are performed to assess the internal accuracy of the two networks. Some initial numerical tests based on GPS and leveling measurements are presented and the goals of the project are analyzed.

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1. INTRODUCTION

The total of the technical work of a country is based on well established horizontal reference networks as well as vertical ones. The knowledge of the location where an event took place (e.g., natural disaster, crustal deformations, and small distortions of a construction) is crucial to a crisis management. On the other hand, the precise knowledge of an incident place is possible to lead to more equitable confrontation from the authorities. With the applications of modern technology such as GNSS/GPS, the horizontal determination is feasible with particularly high precision. The horizontal control networks are measured and validated continuously and their accuracy is particularly high. With respect to the vertical control networks their confrontation is different: the effect of the earth's gravity field, due to the inherent connection of the height information with the direct natural environment, complicates the processes of measurement and utilization of leveling data (Vergos et al. 2006, Vergos 2011). The importance of height information is extremely high; it is enough one to think the human activities dependent on this. The exploitation of surface water resources as well as underground ones, the construction of large technical infrastructures (dams, bridges), as well as the decision-making on environmental issues require as much as possible precise and henceforth reliable hypsometric information. In combination, therefore, with the horizontal position the height data complete our knowledge for the location of an incident in the natural environment where we live and act.

The evaluation of the Hellenic vertical network is the main objective of this work. Height information of high accuracy and reliability in a common reference system is essential. Especially today, with the pan-European effort for the establishment of a common European Vertical Network, the validation of the Hellenic vertical network seems a one-way road decision. In order to underline the importance of the reference systems unification, we mention that the International Association of Geodesy (IAG) established several sub-Commissions that are responsible for the definition and realization of continent-wide geodetic reference systems. For Europe the corresponding sub-Commission is EUREF, which has introduced the European Terrestrial Reference System of 1989 (ETRS89) and the European Vertical Reference System (EVRS). The realization of ETRS89 in Greece has been established through the Hellenic Positioning System (HEPOS) (Katsampalos et al., 2009). During the next years the connection of the vertical datum with Europe has to be done; this is also a European Community directive under the name "INSPIRE". Before the connection, the validation of the vertical network has to be carried out.

2. THEORETICAL BACKGROUND

The first-order vertical control network of Greece was established and measured by the Hellenic Military Geographic Service from 1963 to 1986. On the other hand, the points of the Hellenic trigonometric network have some height information, which was obtained by means of trigonometric leveling. This vertical information has not been systematically validated since its creation, although relevant efforts have been made during the evaluation of EGM2008 (Kotsakis et al. 2008a, 2008b). Thus, the validation of the vertical reference network before the establishment of the European interconnection is essential. In particular, Greece has not been connected yet with any of the unified vertical control systems, resulted a major difficulty in dealing with cross-border problems, relating to transmission of raw materials as well as with road and rail transportations. A prerequisite for the Hellenic vertical datum integration is its evaluation and the use of new technologies for its continuous update. The validation of the height data must be based on the interpretation of inner accuracy solution and the external control using heterogeneous data. The leveling problem in modern times has been transferred from classical terrestrial solutions to the introduction of new methods based on the dipole of high accuracy and fast evaluation. This dipole can lead to continuously updating information for reference point variations and introduce the necessity of decision models through a GIS application.

The need for separation between horizontal and vertical positioning derives from the different accuracy provided by the terrestrial observations. Horizontal directions are measured with increased accuracy with respect to the vertical ones. This is due to the atmospheric refraction effect. The abovementioned event introduces greater uncertainty to the vertical positioning. This is why classical geodetic observations are divided into horizontal directions and distances for horizontal positioning and spirit leveling measurements for vertical positioning. Hypsometric data are referenced to suitable level surfaces. These surfaces represent characteristic elements of the observation environment (see also Figure 1). A characteristic level surface is the MSL. This surface represents the traditional connection of all human activities with the natural environment. Practically, it is the common knowledge that the MSL is a zero-height surface. Theoretically speaking, MSL in a global scale constitutes a balance surface of waters, i.e., an equipotential surface of Earth's gravity field. In this manner, the concept of geoid as a height reference surface is introduced. The geoid is an equipotential surface of the Earth's gravity field that is approached by the MSL in global scale, provided that the effects of tides and marine currents are removed. In well-defined national vertical control network, heights are referenced in a datum point of zero altitude. Usually, the zero-height point is defined by local MSL observations from tide gauges records. In reality, the sea-level change is measured from a conventionally elected level, which is considered constant: the tide gauge zero. Another reference surface used is the ellipsoid of revolution. The ellipsoid is not a physical surface and is used only as a model of the Earth's surface for the horizontal positioning, due to the simplicity of its mathematical relations. The ellipsoid is the reference surface utilized by the geodetic satellite missions. The data of such missions will be used for the validation of the current vertical network. The main height reference surfaces used in the proposed act as well as the measurements (satellite or terrestrial) applied is depicted in Figure 1, where the triplet of heights under investigation are outlined as: a) the orthometric height (H) being the distance along the plump line from Earths' surface to the geoid, b) the ellipsoidal height (h) being the distance along the vertical from Earths' surface to the reference ellipsoid and c) the geoid height being the distance along the vertical from the geoid to the reference ellipsoid (Tziavos and Andritsanos, 1999).

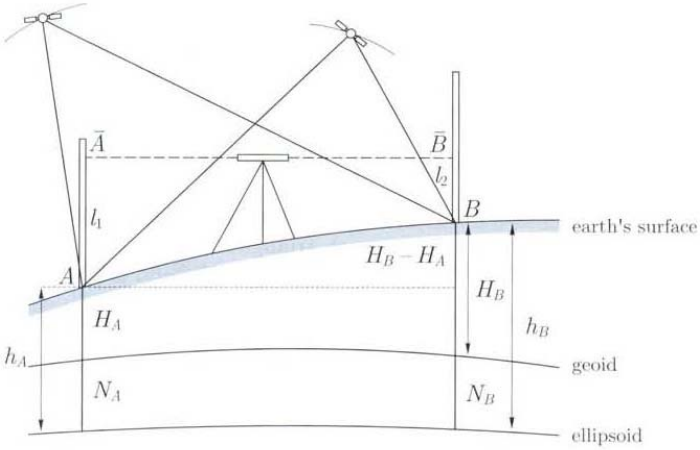

Figure 1: Height reference surfaces (Credits: Hofmann-Wellenhof and Moritz, 2005)

3. DESCRIPTION OF PROJECT

The lack of systematic evaluation of the Hellenic vertical reference system (VRS) and the consequent need for its validation dictates the main focus of the project. To this respect, two study areas have been selected, one in Attica and another in Thessaloniki, in order to investigate the deficiencies of the Greek VRS. Within the VRS validation, recent satellite and classical terrestrial data from the latest gravity-field dedicated satellite missions of GOCE and GRACE will be used, in order to determine the deviations of the Greek VRS w.r.t. a global vertical datum.

The work carried out is at the frontiers of modern geodetic and surveying research, given the immediate necessity for the unification of national VRS's to a global vertical system. The latter is of main importance to all fields of geosciences if one considers that the vertical dimension in geolocation is the most problematic one in terms of achievable accuracy. A similar integrated validation procedure with the combination of a large number of heterogeneous data has not been implemented in Greece. With the methodology outlined in the present work, the continuous validation of height control networks is possible through the assimilation of new terrestrial as well as satellite data into the algorithms.

3.1 GPS/Leveling data

The entire work carried out within the "ELEVATION" Project was conducted in two investigation areas, the prefectures of Attica and Thessaloniki, with the areas under study being geographically determined by their administrative coverage and topographic features. Thus, the region in Attica is bounded north and west by its administrative borders and south and east by the coastline. The study area in Thessaloniki is bounded north, northeast and northwest by its administrative borders, while southwest is surrounded by Strymonikos Gulf and southeast by the Thermaikos Gulf. Figure 2 illustrates the two areas under study.

Figure 2: The areas under study in Attica (left) and Thessaloniki (right) (Google Earth).

As already mentioned, the present work focuses on the exploitation of the vertical component in geodetic positioning, i.e., in order to investigate its influence on gravity field and geoid modeling as well as to classical surveying and cartographic project. The height information is based on two types of data: (a) geoid heights from local gravimetric models and global geopotential models and (b) satellite and conventional geodetic measurements for the determination of ellipsoidal and Helmert-type orthometric heights, respectively. The latter types were to be determined through dedicated GPS campaigns, spirit leveling and special trigonometric leveling (Balodimos et al., 2007) measurements. Due to earlier work of the research groups involved in the project, all three types of height information were available for a number of benchmarks in both areas under study (see Figure 3, where the existing database is presented), therefore the work carried out referred to additional measurements in order to fill-in the areas under study.

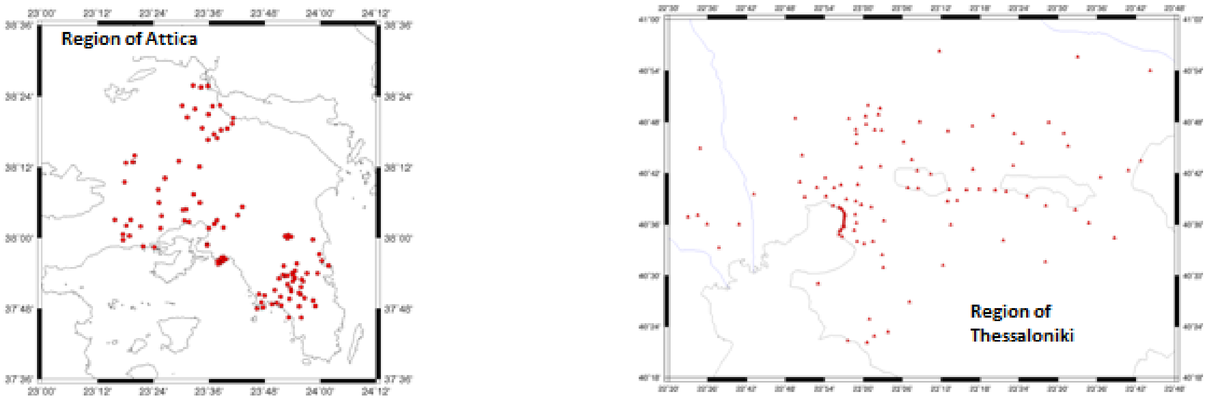

Figure 3: Existing height data on benchmarks in the regions of Attica (left) and Thessaloniki (right).

3.1.1 <u>Leveling data identification and collection</u>

Given the availability of a number of GPS/Leveling benchmarks with collocated GPS and leveling observations, the first step referred to the determination of new benchmarks (BMs) to be measured. The new BMs were selected from the National Trigonometric and Leveling Network, established by the Hellenic Military Geographic Service (HMGS) in order to guarantee the connection to the national horizontal and vertical networks. Figures 4 and 5 depict the existing Horizontal and Leveling Networks in the two areas under study as they are given by HMGS (www.gys.gr). As it can be seen the Leveling Network comprises of less points than the Trigonometric Network so their availability was crucial for planning the Elevation Project given that a large portion of the Greek Leveling Network BMs has been destroyed.

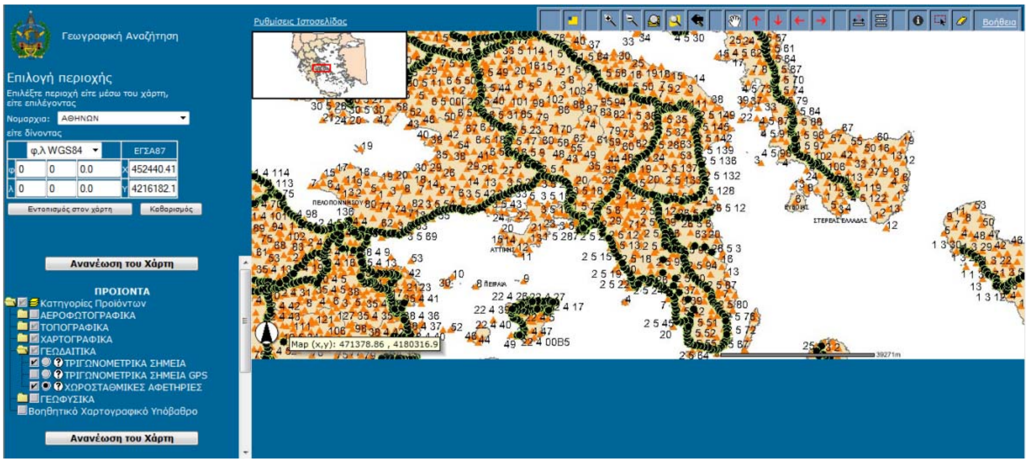

Figure 4: The Trigonometric and Leveling Network in the region of Attica (www.gys.gr).

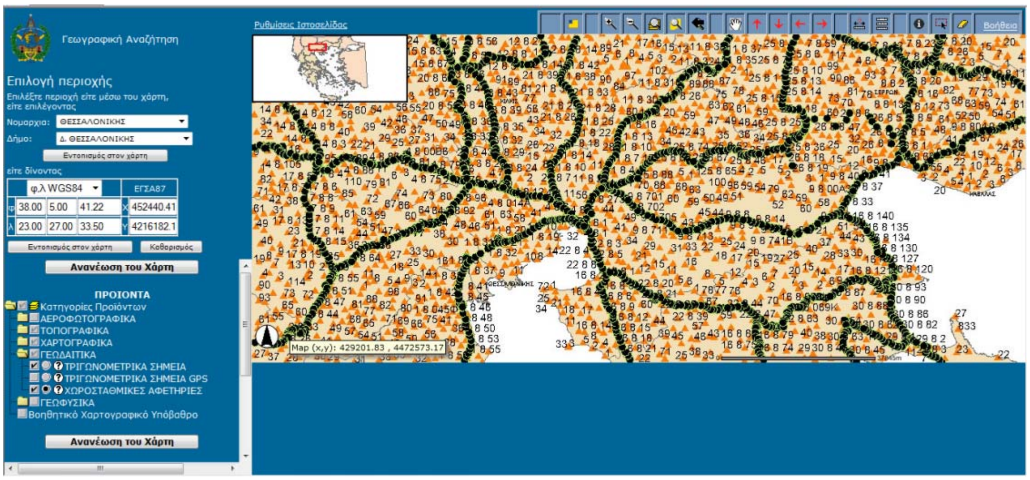

Figure 5: The Trigonometric and Leveling Network in the region of Thessaloniki (www.gys.gr).

Given that the trigonometric and leveling networks of HMGS are not systematically maintained, many BMs, even though they are shown in the respective geoindex service, do not exist anymore. Therefore, the first step referred to a reconnaissance campaign in order to identify BMs that still exist and verify that they are in good condition to be measured (monument not destroyed or relocated, etc.). The height BMs reconnaissance was based on descriptions of their location provided by HMGS along with an approximate estimation of their geodetic coordinates. Overall six tracks, comprising of a total number of 157 height BMs, were followed so as to identify height benchmarks in Attica. From these, only the 27 were found including three points that were inappropriate to use. In the region of Thessaloniki overall five tracks, comprising of a total number of 28 height BMs, were followed in order to indentify the height benchmarks. From these, 10 points were found; all of them being adequate for measurements. Figure 6 depicts the 27 height BMs which were found in the region of Attica and the 10 height BMs in the region of Thessaloniki.

Figure 6: The height BMs that were found in the region of Attica (left) and Thessaloniki (right)

Of the total number of height benchmarks that were found after the research in the two investigation areas only a part of them were chosen for conducting the leveling measurements. The two methods that were used in order to determine the orthometric heights are classic spirit leveling and special trigonometric leveling. The plan of leveling measurements is based on the prevailing conditions of each investigation area, so that Table 1 summarizes the leveling measurements in the regions of Attica and Thessaloniki. It should be noted, that for most leveling BMs, since GPS measurements cannot be performed directly on them, collocated BMs were established at short distances in order to measure both orthometric as well as ellipsoidal heights for all of them.

In order to reassess the leveling network in the investigation areas of Attica and Thessaloniki a combination of satellite and ground based techniques were used for the determination of orthometric height differences. Specifically, the height differences that were selected and measured in Attica were ten and in Thessaloniki twelve. As already have mentioned, the two types of techniques that were applied are the classical spirit leveling and the special trigonometric leveling. The two techniques were applied not only between height benchmarks but also between benchmarks and height benchmarks. Table 1 presents in detail the regions, the techniques and the equipment of the leveling measurements which were used in the areas under study in Attica and Thessaloniki.

Table 1: The regions, the techniques and the equipment of the leveling measurements in Attica and Thessaloniki.

Leveling Process No	Date	Region	Starting Point ID	Ending Point ID	Technique *	Equipment
ATHENS						
1	09/10	Ano Souli	5161020148	5161020147	CSL	Topcon DL-101C
2	09/10	Rafina	5161020130	161017	CSL	Topcon DL-101C
3	13/10	Rafina	5161020130	5161020131	STL	Leica TCR 1202
4	13/10	Nea Makri	5161020135	5161020136	STL	Leica TCR 1202
5	16/10	Grammatiko	5161020152	161105	STL	Leica TCR 1202
6	16/10	Kapandriti	5161020163	5161020161	STL	Leica TCR 1202
THESSALONIKI						
1	11/09	Peristera	8063220022	63067	CSL	Leica Spr. 150
2	11/09	Epanomi	8116220021	8116220021_101gg	CSL	Leica Spr. 150
3	11/09	Peristera	8063220023	8063220023_103gg	CSL	Leica Spr. 150
4	11/09	Peristera	8063220022	8063220022 _102gg	CSL	Leica Spr. 150
5	11/09	Kardia	8103160009	8103160009_100gg	CSL	Leica Spr. 150
6	11/09	Agios Athanasios	8118040011	8118040011_106gg	CSL	Leica Spr. 150
7	11/09	Gefira	8303030021	8303030021_107gg	CSL	Leica Spr. 150
8	12/09	Proxoma	8176030029	8176030029_109gg	CSL	Leica Spr. 150
9	12/09	Proxoma	8176030029	176021	CSL	Leica Spr. 150
10	12/09	Dorkada	8187110022	8187110022 _105gg	CSL	Leica Spr. 150
11	12/09	Koufalia	8176200040	8176200040 _108gg	CSL	Leica Spr. 150
12	12/09	Kartere	8187110298	8187110298_104gg	CSL	Leica Spr. 150
13	11/09	Peristera	8063220022	63067	STL	Topcon GTS212
14	11/09	Epanomi	8116220021	8116220021_101gg	STL	Topcon GTS212
15	11/09	Peristera	8063220023	8063220023_103gg	STL	Topcon GTS212
16	11/09	Peristera	8063220022	8063220022 _102gg	STL	Topcon GTS212
17	12/09	Kardia	8103160009	8103160009_100gg	STL	Topcon GTS212
18	12/09	Agios Athanasios	8118040011	8118040011_106gg	STL	Topcon GTS212
19	12/09	Gefira	8303030021	8303030021_107gg	STL	Topcon GTS212
20	12/09	Proxoma	8176030029	8176030029_109gg	STL	Topcon GTS212
21	12/09	Proxoma	8176030029	176021	STL	Topcon GTS212
22	12/09	Dorkada	8187110022	8187110022 _105gg	STL	Topcon GTS212
23	12/09	Koufalia	8176200040	8176200040 _108gg	STL	Topcon GTS212
24	11/09	Kartere	8187110298	8187110298_104gg	STL	Topcon GTS212
* CSL : Classical Spirit Leveling STL: Special Trigonometric Leveling						

3.1.2 GPS data identification and collection

The GPS data to be collected refer to ellipsoidal heights over the previously outlined network of identified trigonometric and leveling BMs as well as over the newly established reference points close to the leveling BMs. The latter were located in a short distance from the height benchmarks of the national leveling network for validation and quality control. From the 27 vertical benchmarks which were found in Attica, 9 were selected to be measured. Furthermore, in Thessaloniki all the available vertical benchmarks were suitable for GPS and leveling observations. After the selection of the appropriate height benchmarks, the selection of the benchmarks of the national trigonometric network took place. In order to guarantee the redundancy of the measurements, alternative benchmarks were selected, within some eligible areas for each point. Figures 7 and 8 depict the location of the benchmarks along with the confidence regions where alternative BMs would be sought.

Figure 7: Map of the Attica test area, with the location of the groups of alternative benchmarks (red ellipsoids), the existing height benchmarks (red circles) and the already available benchmarks of the national trigonometric network (green triangles).

All GPS measurements have been collected in static mode and have been connected to the HEPOS stations. The HEPOS stations near Attica and Thessaloniki were used as reference stations for the GPS measurements in order to calculate the coordinates of the benchmarks in the HTRS07 datum, providing high accuracy and homogeneity. Besides, HEPOS stations provide several other advantages. First of all, they ensure smaller baseline lengths compared with the EPN (EUREF Permanent Network) stations, as there is a dense network all over Greece and especially in Attica and Thessaloniki. In the case of EPN, the only available stations would be AUT1 in Thessaloniki and NOA1 in Attica, leading to baseline lengths greater than 50 km. On the contrary, the HEPOS network ensures smaller baselines, in the order of 25 km, which allow the determination of highly accurate geometric heights. Moreover, HEPOS data are available in any observation rate unlike the EPN data which are provided at an observation rate of 30 sec. Figure 9 depicts the HEPOS stations that were used in this work.

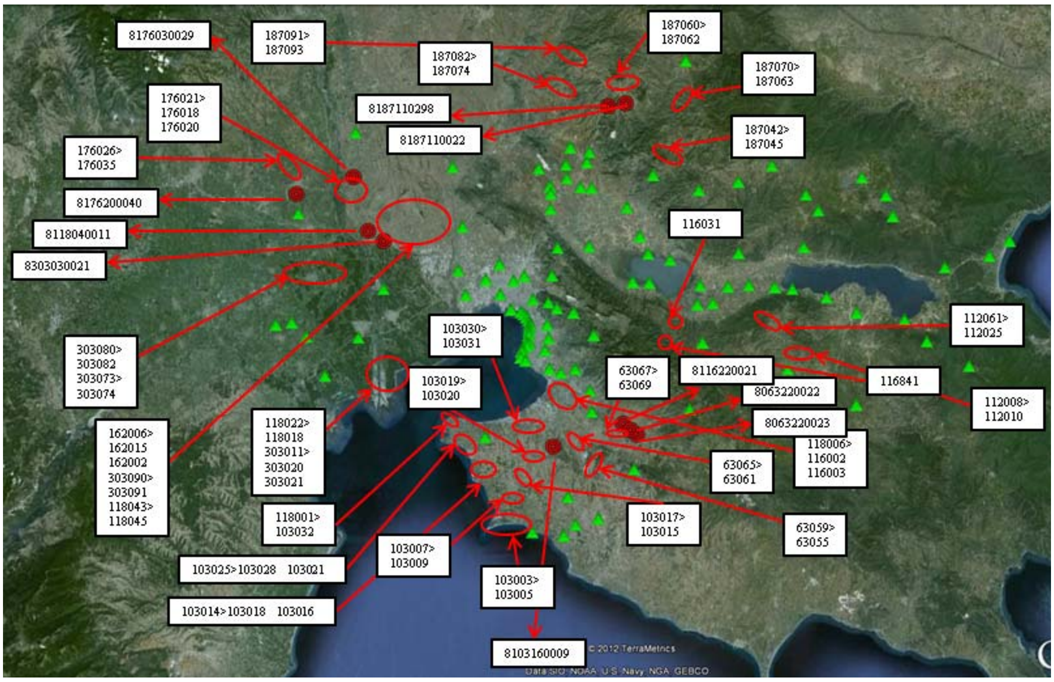

Figure 8: Map of the Thessaloniki test area, with the location of the groups of alternative benchmarks (red ellipsoids), the existing height benchmarks (red circles) and the already available benchmarks of the national trigonometric network (green triangles).

For each area under study, dual frequency receivers were used as it is mandatory for baselines longer than 10 Km, in order to reduce the influence of the ionosphere. For the GPS measurements in Attica the appropriate equipment of the Geodesy-Surveying Laboratory of the Technological Educational Institute of Athens was used. Regarding the area of Thessaloniki, the Department of Geodesy and Surveying of the School of Rural and Surveying Engineering of the Aristotle University of Thessaloniki provided the necessary equipment.

Figure 9: The HEPOS stations which cover the investigation areas of Attica (left) and Thessaloniki (right).

Table 2 presents the specifications of the equipment that used in the two investigation areas. The TOPCON HiperPro receiver offers 40 channels and provides full wavelengths as well as code measurements on L2 frequency under A-S (Anti-Spoofing) conditions. With regard to performance specifications, TOPCON HiperPro receiver is characterized by an accuracy of 3 mm + 0.5 ppm (horizontally) and 5 mm + 0.5ppm (vertically). On the other hand, LEICA SR520 receiver offers 20 channels and similarly with TOPCON receiver, it provides full wavelengths as well as code measurements on L2 frequency under conditions of A-S. The accuracy is of the order of 3 mm + 0.5ppm for static survey and 5 mm + 1 ppm for rapid static. Figures 10 and 11 outline the set-up used for the GPS static measurements on HMGS trigonometric BMs in Attica and Thessaloniki, respectively.

Table 2: GPS equipment that used in the areas of Attica and Thessaloniki.

Investigation Area	**Receiver Type**	**Antenna Type**
Attica	TOPCON HiperPro	TOPCON HiperPro
Thessaloniki	LEICA SR520	LEICA AT502

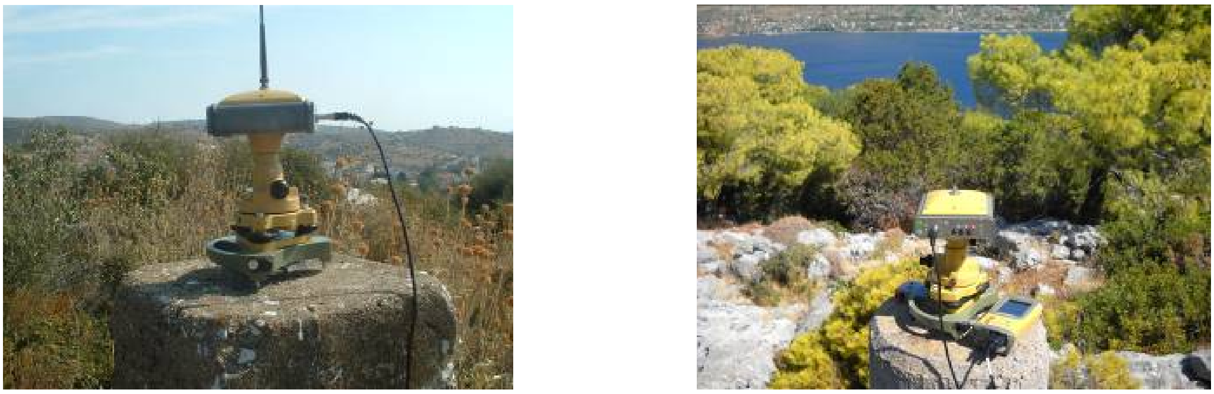

Figure 10: The TOPCON HiperPro receivers during the GPS measurements on BMs in Attica.

Figure 11: The LEICA SR520 receivers during the GPS measurements on BMs in Thessaloniki.

The GPS measurements in both investigation areas have been conducted following commonly defined parameters, i.e. occupation time of at least 60 minutes, logging rate 15 sec and elevation mask 10^o. The antenna height measurements are characterized by an accuracy of ±1 mm, while the reference point was at the top of the benchmark. The uniform equipment and procedure for the antenna height measurements provide homogeneity and high accuracy, with variations of the order of 2-3 cm.. Considering the above, the errors in reading or typing the antenna height, which are a common source of errors in GPS measurements, can be avoided. The next section outlines the results from the two leveling methods employed to determine orthometric heights as well as the analysis of the GPS processing for the determination of geodetic coordinates.

4. NUMERICAL ANALYSIS

4.1 Leveling results and analysis

As far leveling is concerned, traditional spirit and special trigonometric leveling have been employed. Tables 3 and 4 summarize the results acquired over the leveling baselines w.r.t. the determination of the height difference between a reference and a measuring point. Given the superiority of spirit leveling, it is interesting to notice that the differences between spirit and trigonometric leveling achieved range from a few mm up to ±3.2cm for the longer distances. These data will be used in height combination schemes for the adjustment between orthometric, ellipsoidal and geoid heights towards the unification of the Greek Vertical Reference System (VRS) (Tziavos et al. 2012a, b; Vergos and Sideris 2002, Vergos et al. 2007). Therefore the inherent consistency of the height information as well as proper error modeling, which can be achieved from spirit leveling through the baseline length, are vital.

Table 3: Leveling results for the investigation area of Attica.

Leveling Process No	Region	Starting Point ID	Ending Point ID	S* (km)	Technique*	Orthometric Height Difference*
1	Ano Souli	5161020148	5161020147	1.13	CSL	-48.752
2	Rafina	5161020130	161017	0.60	CSL	3.754
3	Rafina	5161020130	5161020131	0.95	STL	-22.105
4	Nea Makri	5161020135	5161020136	1.23	STL	-22.638
5	Grammatiko	5161020152	161105	0.40	STL	8.206
6	Kapandriti	5161020163	5161020161	3.47	STL	27.751
*S: Distance CSL : Classical Spirit Leveling STL: Special Trigonometric Leveling						

Table 4: Leveling results for the investigation area of Thessaloniki.

Leveling Process No	Region	Starting Point ID	Ending Point ID	S* (km)	DH_{CSL} (m)	DH_{STL} (m)	DH_{CSL}-DH_{STL} (m)
1	Peristera	63067	8063220022	0.32	4.817	4.785	0.032
2	Epanomi	8116220021	8116220021_101gg	0.06	0.399	0.395	0.004
3	Peristera	8063220023	8063220023_103gg	0.106	0.796	0.806	-0.010
4	Peristera	8063220022	8063220022 _102gg	0.032	0.123	0.125	-0.002
5	Kardia	8103160009	8103160009_100gg	0.04	0.233	0.231	0.002
6	Ag. Athan.	8118040011	8118040011_106gg	0.077	-0.562	-0.562	-0.000

7	Gefira	8303030021	8303030021_107gg	0.055	-0.447	-0.446	-0.001
8	Proxoma	8176030029	8176030029_109gg	0.071	-2.064	-2.066	0.002
9	Proxoma	8176030029	176021	0.3	10.536	10.548	-0.012
10	Dorkada	8187110022	8187110022 _105gg	0.091	-2.222	-2.201	-0.021
11	Koufalia	8176200040	8176200040 _108gg	0.02	0.556	0.549	0.007
12	Kartere	8187110298	8187110298_104gg	0.028	0.728	0.737	-0.009
* CSL : Classical Spirit Leveling STL: Special Trigonometric Leveling							

4.2 GPS results and analysis

In order to determine the geodetic coordinates of all the GPS BMs in HTRS07, HEPOS reference stations have been used for each investigation area. Each point has been connected to two HEPOS stations. During GPS processing three different approaches have been followed. First, the benchmarks and the newly established points were solved from the nearest HEPOS reference station. Afterwards, the measured benchmarks and points were solved from the next nearest HEPOS reference station. Finally, a least squares adjustment has been computed for each point using the two baselines connecting the point to the HEPOS stations. Different GPS processing software packages have been used for the baseline reduction, with the results presented herein coming from the Leica Geo Office (LGO) program. Figures 12 and 13 depict the processed baselines for both areas. So that in each station the geodetic coordinates are determined as an adjusted solution from both the nearest and next nearest HEPOS station.

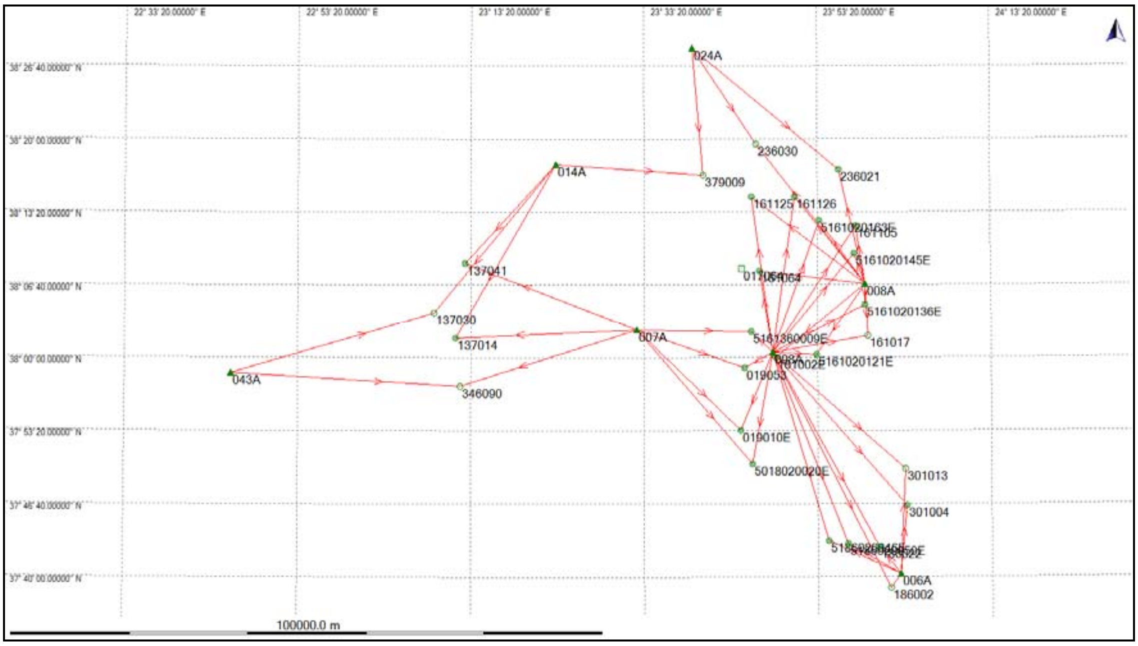

Figure 12: Baselines (short and long) in Attica and processing results (LGO).

Tables 5 and 6 present the geodetic coordinates (X, Y, Z) in HTRS07 as well as the standard deviations (std) of all the measured benchmarks and points in Attica and Thessaloniki, including both the nearest and the furthest HEPOS reference station. In these tables, both the coordinates and the standard deviations of the final solutions are provided. It is of worth mentioning that some points were not solved from both stations because the averaging limit was exceeded. For these points in both areas (outlined with red in the Tables) the problem in solving simultaneously form both HEPOS stations can be attributed to limited satellite visibility due to obstacles like trees and disrupted L2 measurements due to electromagnetic interferences in the areas of the BMs.

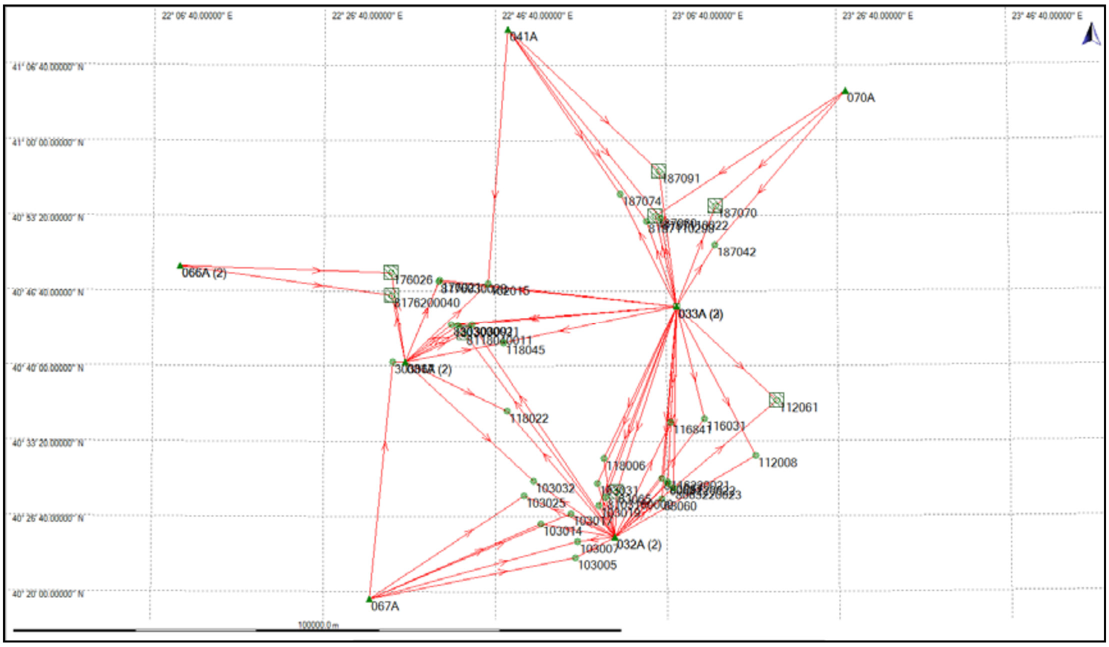

Figure 13: Baselines (short and long) in Thessaloniki and processing results (LGO).

Table 5: Leica Geo Office results for both the shortest and the longest baselines in Attica.

Point Id	X (m)	Y (m)	Z (m)	std(X) (m)	std(Y) (m)	std(Z) (m)
17064	0	0	0	0.0000	0.0000	0.0000
019010E	4613547.0539	2029159.6199	3895771.1204	0.0190	0.0086	0.0163
19053	4607522.5128	2027123.8561	3904262.2811	0.0114	0.0051	0.0105
137014	4624209.4675	1981217.3049	3908357.9147	0.0163	0.0074	0.0180
137030 (014A)	4622964.6992	1976765.5018	3911403.3561	0.0016	0.0007	0.0014
137041	4616154.9471	1979488.8528	3918081.4371	0.0127	0.0109	0.0118
161002E	4604412.8482	2031604.7214	3905583.0883	0.0020	0.0034	0.0013
161017 (008A)	4595913.4895	2044840.0840	3908391.8324	0.0008	0.0005	0.0009
161064	4597228.7009	2025478.8403	3917234.4837	0.0237	0.0115	0.0203
161105	4586413.9092	2038335.9746	3923156.6757	0.0085	0.0071	0.0069
161125	4590576.0486	2021108.4579	3927088.1604	0.0071	0.0109	0.0060
161126	4587973.3529	2027855.3390	3927308.2137	0.0113	0.0054	0.0097
186002 (006A)	4618223.0634	2058827.9960	3874789.1905	0.0006	0.0003	0.0004
186022	4615211.4360	2055422.3103	3880355.0791	0.0075	0.0034	0.0095
236021	4581915.2099	2033374.5249	3930571.9198	0.0246	0.0148	0.0225
236030 (008A)	4585143.1414	2019476.6059	3933839.0248	0.0022	0.0014	0.0021
301004	4609355.4433	2057853.8783	3885916.1798	0.0171	0.0076	0.0197
301013 (006A)	4605929.0987	2056182.1690	3890738.5004	0.0013	0.0007	0.0009
346090 (007A)	4628184.1549	1983816.4342	3901654.3515	0.0016	0.0009	0.0013

379009 (014A)	4591750.5756	2012634.0687	3929840.4948	0.0015	0.0007	0.0011
5018020020E	4615857.6783	2032320.5692	3891353.1940	0.0204	0.0108	0.0171
5161020121E	4601281.1458	2037784.4608	3905935.6226	0.0165	0.0077	0.0141
5161020136E	4593049.6215	2043003.0354	3912569.4115	0.0095	0.0042	0.0083
5161020145E	4588934.6792	2039212.7396	3919371.4087	0.0213	0.0098	0.0183
5161020163E	4588360.5715	2032567.5184	3923889.1101	0.0164	0.0100	0.0158
5161360009E	4603436.9788	2026684.6893	3909049.5178	0.0042	0.0045	0.0049
5186020046E	4617943.1065	2047301.4261	3881105.3377	0.0228	0.0116	0.0200
5186020050E	4616939.0250	2050325.4874	3880683.3359	0.0125	0.0073	0.0173

Table 6: Leica Geo Office results for both the shortest and the longest baselines in Thessaloniki.

Point Id	X (m)	Y (m)	Z (m)	std(X) (m)	std(Y) (m)	std(Z) (m)
103005	4480666.0949	1895782.9751	4110619.2829	0.0062	0.0089	0.0051
103007	4478991.1303	1895435.8957	4112635.9879	0.0072	0.0168	0.0011
103014	4479612.5713	1889120.4670	4114772.6982	0.0105	0.0227	0.0047
103017	4476709.8245	1893380.9070	4116115.5248	0.0060	0.0045	0.0055
103019	4474196.8246	1897206.0092	4117252.7451	0.0053	0.0035	0.0056
103025	4477908.8600	1885456.4768	4118343.8225	0.0080	0.0070	0.0087
103031	4472091.0924	1896051.6572	4119857.2543	0.0088	0.0040	0.0107
103032	4475930.0026	1886301.1065	4120124.2848	0.0150	0.0181	0.0137
112008	4459560.7816	1919082.2449	4123644.9935	0.0186	0.0167	0.0168
112061 (033A)	4452624.1769	1920013.1342	4130364.2539	0.0031	0.0016	0.0022
116031	4459072.8908	1909753.7084	4128127.1158	0.0219	0.0103	0.0244
116841	4462126.5674	1904951.1834	4128207.4375	0.0093	0.0127	0.0081
118006	4469107.6152	1896050.6803	4122971.3521	0.0167	0.0095	0.0158
118022	4470682.3808	1879348.7361	4128840.1563	0.0184	0.0082	0.0204
118045	4464238.6666	1875971.6023	4137321.9046	0.0102	0.0125	0.0110
162015	4459475.8444	1871330.0809	4144860.2808	0.0075	0.0053	0.0091
176021	4462120.7138	1863710.4955	4145221.6803	0.0066	0.0049	0.0061
176026 (031A)	4464363.8174	1856104.3600	4146148.7320	0.0010	0.0006	0.0011
187042	4441500.8104	1904100.2864	4149974.3977	0.0041	0.0041	0.0046
187060 (033A)	4442363.9366	1893855.9793	4153530.6041	0.0023	0.0010	0.0013
187070 (033A)	4437527.7375	1902564.9604	4154731.9948	0.0008	0.0006	0.0009
187074	4442289.2703	1887645.5560	4156175.6318	0.0194	0.0118	0.0238
187091 (041A)	4437706.7257	1892654.8102	4159146.9497	0.0017	0.0008	0.0019
303067	4473122.9709	1860044.5646	4134906.4635	0.0057	0.0026	0.0068
303090	4465346.0160	1868379.1500	4139556.9686	0.0158	0.0069	0.0148
303091	4464374.2639	1870519.5410	4139676.3865	0.0094	0.0042	0.0102
63060	4469475.5286	1906438.7224	4117985.9686	0.0211	0.0090	0.0241
63065 (032A)	4471702.9712	1899377.8031	4118859.6266	0.0008	0.0005	0.0007
63067	4467325.5952	1906701.8451	4120072.9194	0.0041	0.0019	0.0039
8063220022	4467482.2391	1906730.4750	4119885.3973	0.0122	0.0073	0.0113
8063220023	4467579.9136	1907762.5726	4119308.8459	0.0084	0.0066	0.0080
8103160009	4472994.6822	1897932.8837	4118155.5474	0.0237	0.0107	0.0256
8116220021	4467440.3278	1905593.2258	4120443.9714	0.0027	0.0030	0.0030
8118040011 (031A)	4465679.9842	1869758.4022	4138544.4068	0.0009	0.0006	0.0008
8176030029	4462231.6043	1863678.7380	4145105.9953	0.0089	0.0047	0.0093
8176200040 (031A)	4466585.2522	1857132.3179	4143241.2579	0.0014	0.0007	0.0009
8187110022	4442217.1203	1894721.8215	4153140.3566	0.0147	0.0100	0.0137
8187110298	4443353.2857	1892754.9310	4152810.5781	0.0188	0.0080	0.0220
8303030021	4465695.1732	1867417.3088	4139579.6800	0.0051	0.0031	0.0059

Given the solution with all possible baselines between the measured points and the HEPOS stations, closing error of the loops that are created separately for each investigation area have been computed, along with the relative errors. Tables 7 and 8 present, for Attica and Thessaloniki respectively, the closing and relative errors for all BMs measured. It is interesting to notice that the relative error ranges from 0.04 ppm up to 3.71 ppm, indicating the quality of the GPS measurements.

Table 7: Loops results in the investigation area of Attica (LGO).

Loop	Closing error (cm)	Length (km)	Relative error (ppm)
019010E-007A-098A	0.34	62.03	0.0548
019053-007A-098A	9.03	48.08	1.8781
137014-007A-014A	0.75	95.75	0.0783
137030-014A-043A	3.99	133.50	0.2989
137041-014A-007A	6.48	85.03	0.7621
161002-098A-008A	1.39	40.18	0.3459
161064-098A-008A	2.62	51.49	0.5088
161105-008A-098A	0.41	54.90	0.0747
161125-008A-098A	7.09	70.36	1.0077
161126-098A-008A	0.28	65.12	0.0430
161017-098A-008A	0.54	44.63	0.1210
186022-098A-006A	6.82	86.11	0.7920
236021-008A-024A	22.63	101.16	2.2371
236030-008A-024A	24.28	98.62	2.4620
301004-006A-098A	0.18	88.77	0.0203
301013-006A-098A	33.6	90.43	3.7156
346090-007A-043A	24.97	138.98	1.7967
379009-014A-024A	1.34	76.45	0.1753
5018020020E-098A-007A	2.56	72.23	0.3544
5161020136E-008A-098A	0.86	40.52	0.2122
5161020145E-098A-008A	1.71	46.61	0.3669
5161020163E-008A-098A	4.08	56.34	0.7242
5161360009E-098A-007A	1.19	47.82	0.2488
5186020046E-098A-006A	17.52	89.41	1.9595
5186020050E-098A-006A	1.36	87.87	0.1548

Table 8: Loops results in the investigation area of Thessaloniki (LGO).

Loop	Closing error (cm)	Length (km)	Relative error (ppm)
103005-32-67	3.51	83.39	0.4209
103007-32-67	21.81	83.24	2.6203
103014-32-67	3.02	84.67	0.3567
103017-32-67	21.55	85.71	2.5143
103019-32-33	14.44	80.17	1.8011
103025-32-67	0.88	88.53	0.0994
103031-32-33	1.56	80.38	0.1941
103032-31-32	1.22	89.85	0.1358
112008-32-33	3.38	93.76	0.3605
116031-32-33	2.12	82.67	0.2565
116841-32-33	1.9	79.31	0.2396
118006-32-33	0.44	79.93	0.0551
118022-31-32	0.42	90.66	0.0463
118045-31-33	2.59	91.08	0.2844
162015-31-41	9.16	117.89	0.7770
176021-31-33	2.63	99.35	0.2647

187042-33-70	2.47	90.18	0.2739
187074-33-41	4.61	106.75	0.4318
303067-31-67	0.45	80.36	0.0560
303090-31-33	1.68	92.18	0.1823
303091-31-32	0.31	99.53	0.0311
63060-32-33	1.95	80.84	0.2412
63067-32-33	3.57	80.67	0.4425
8176030029-31-33	0.82	99.24	0.0826
8063220022-32-33	0.92	80.72	0.1140
8063220023-32-33	1.08	81.60	0.1323
8103160009-32-33	0.4	79.39	0.0504
8116220021-32-33	1.32	79.92	0.1652
8187110022-33-41	4.32	107.93	0.4003
8187110298-33-41	10.74	107.08	1.0030
8303030021-31-33	2.79	92.40	0.3019

5. CONCLUSIONS – FUTURE PLANS

The need of a detailed validation of the existing vertical network, which is used in nowadays studies, comes from the demand for increased accuracy. Natural hazards confrontation, via more equitable decisions in crisis situation, can be done using an accurate representation of the physical environment and its interdependency with the human activities. The products of the work carried out will lead geoscientists to a better understanding of the vertical network issues. Vertical networks as geodetic infrastructures provide accurate information about fundamental properties of the Earth as they change over time and has led to many scientific, civil, military, and commercial applications.

Height information has found its part in this multi-disciplinary process, since it always has played an important part in building and running the infrastructure business. Spatial data that is used in the process of modernization of all infrastructures is collected by geodetic methods. Height information is an irreplaceable factor-through engineering task of preparing spatial basis, staking out of different projects and surveying during building works.

This work shows the role of surveyor engineer in spatial information development as well as taking part in property documentation using a well validated vertical control network. In addition, the development of a geographical information system combining height and property information is in our future plan. This system will be used to monitor and record changes in order to prevent illegal constructions, so it will give a new quality level for managing the documents of real estate cadastre.

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