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APPLICATIONS OF MICROSOFT EXCEL - SOLVER FOR HORIZONTAL AND LEVELLING NETWORKS ADJUSTMENT

BY

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Abstract. For rigorous processing of geodetic measurements, to implement the principle of least squares, it is necessary to solve a linearized system of equations, which requires knowledge of the unknown coefficients as partial derivatives of the specific functions. Without the need for the operator to perform this calculation step, Solver application directly determines the optimal solution, which meets the minimum condition imposed. In this case, it is shown how to solve adjustment problems, structured by the method of indirect observations for a triangulation - trilateration network and by the method of conditional observations for a geometric levelling network. Finally, the results are compared to those known from the application of classical methods, suggesting the most appropriate options for using Solver interface.

Keywords: geodetic; network; adjustment; Microsoft Excel, Solver.

1. Introduction

The *Microsoft Excel - Solver* tool, developed by Frontline Systems, Inc. is a standard tool of any *Microsoft Office* product. *Solver* application solves linear and nonlinear programming problems, which are found in various areas

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of science, serving to optimize solutions in an effective way, using a limited spectrum of resources. As a way of functioning, the *Solver* application determines the maximum, minimum or pre-defined value of an aim function by altering some variables selected by the software.

Since problems based on the principle of least squares require minimization, *Solver* application allows using this condition to adjust geodetic networks, whose functional models comprise a number of up to 200 equations.

There is also an improved version called *Premium Solver*, fully compatible with *Microsoft Excel*, which can solve more than 400 nonlinear equations, respectively over 1000 linear equations. In addition, the application can be easily used by users who are not possessing advanced knowledge about the formation of initial equations, linearization process or solving final systems of equations, as necessary in the practice of the usual methods.

The *Solver* application is simple to install, in *Microsoft Excel* software by going to the *File* menu, submenu *Options/Add-Ins*, where you can select *Solver Add-in* and validate the option. Launching of the application is performed from the *Data* menu, located in the toolbar, in the *Analysis* category.

2. Selecting the Options in the Dialog Box of the *Microsoft Excel Solver* Application

After installing and launching the Microsoft Excel Solver application, a dialog box will open and the specific parameters will be completed, depending on the type of problem to be solved.

As outlined in Fig. 1, there are a number of fields, in which are introduced the reference cells from the model designed in Excel worksheet, as well as the cells that will change their values due to running the program.

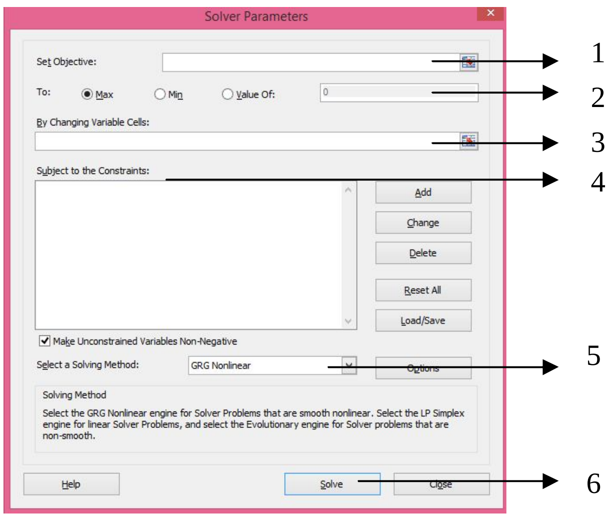

Fig. 1 – Microsoft Excel Solver application parameters.

As a next step, we will present some information about each field separately, and specific settings, where applicable:

1º *Set Objective* – in this box is inserted the target cell from the Excel worksheet, for which there will be a condition of minimum, maximum or convergence to a certain value. The target value of the cell is required to be defined by a formula.

2º *To: Max/Min/Value of* – ticked as follows: *Max*, if desired that the objective cell should point to maximum value; *Min*, if that target cell should tend towards minimum; *Value of*, if that target cell should tend towards a certain value, specifying it in the field on the right.

3º *By Changing Variable Cells* - a reference will be inserted for each variable cell that will change after applying the desired condition and running the program. The nonadjacent references are separated by commas and the variable cells must be related directly or indirectly to the target cell. Up to 200 variable cells can be specified in this field.

4º *Subject to the Constraints* – this is a broad field, in which any necessary restrictions can be introduced. The procedure of adding the restrictions is shown in Fig. 2.

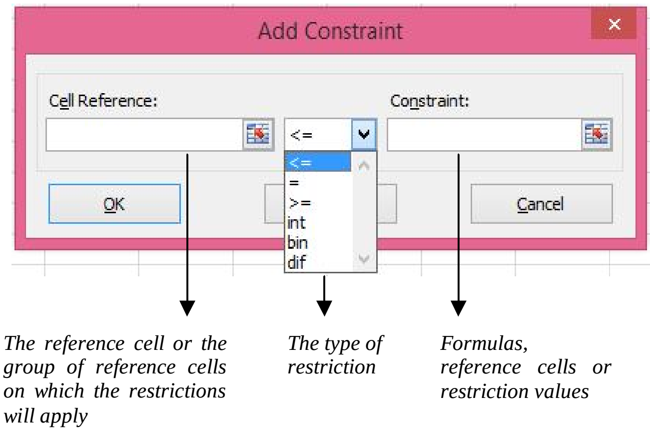

Fig. 2 – Adding restrictions in Microsoft Excel Solver.

5º *Select a Solving Method* – a series of algorithms are used to identify optimal solutions, namely: *GRG Nonlinear*, *Simplex LP* and *Evolutionary*. As highlighted in Fig. 3, there are a number of options available for any of the methods used, regardless of the type of problem, related to generating the result. The user has the possibility to configure the program depending on the required precision, time of run or number of iterations generated. You can also select the option *Show Iteration Results*, which allows viewing the results after each iteration:

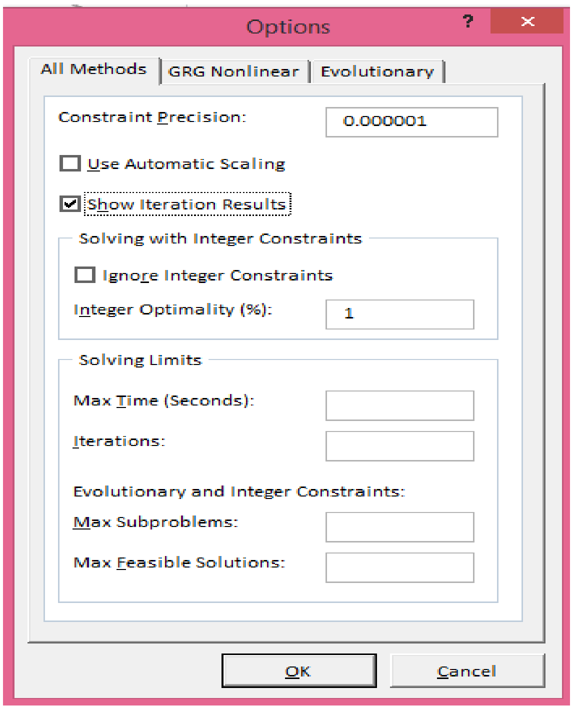

Fig. 3 – Options of the Solver application methods.

a) *GRG method* is an iterative optimization algorithm, which consists finding the local maximum or minimum of a function using the gradient. The gradient in a point of a function represents the direction of maximum growth of that function and is zero in maximum and minimum points. *Reduced gradient method (GRG)* is applied for solving linear programming problems. In addition to the general options of the application, this method provides the user with a number of additional options, aiming the convergence mode, the type of derivative and the size of data population.

b) *The simplex method* for solving linear programming problems can be applied for three or more variables, being essentially a matrix method. It involves a search through the multitude of possible solutions, to find the optimal solution for the objective.

c) *Evolutionary method* is recommended in case of non-homogeneous equations and it uses a variety of genetic algorithms and local search methods, involving searching the solution in the space of all possible solutions, using a population of agents. Search is guided through a function that measures the closeness to the solution. The searching process is based on two main mechanisms: *exploration* (covering different regions in solutions space and collecting the information) and *exploitation* (refining solution, exploiting information gathered in the process of exploration).

6º *Solve* – is the controller, which is called after all fields have been defined and the solving method has been configured. If all conditions are met, the application running successfully, a dialog box will be generated (Fig. 4), the user being able to keep the generated solutions or return to initial values.

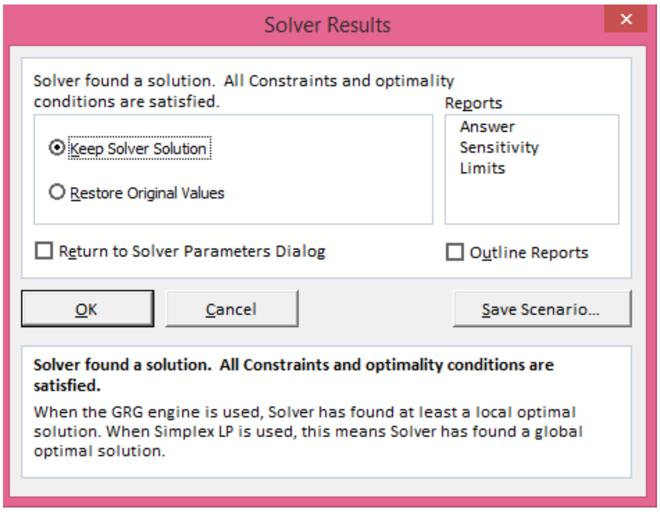

Fig. 4 – Generation of Solver application results.

3. Adjustment of a Horizontal Geodetic Network Using *Microsoft Excel Solver*

The adjustment of horizontal geodetic networks using indirect measurements method was applied to thickening of national and local control networks, but still retains its importance for restricted applications, such as monitoring engineering objectives (Ghilani & Wolf, 2006).

For example, it is considered a triangulation - trilateration network (Fig. 5), consisting of five points (A, B, C, D, E) of known coordinates and five new points (G, H, I, J, K). The measurements were carried out in both of the azimuthal directions (Table 2, column 5) and the distances between the new points as well (Table 3, column 5).

The network adjustment using *Solver* application, structured after indirect observations method is performed by the following steps (Chirilă, 2014):

1. Initial approximations calculation of the network elements

Initial approximated network elements are the rectangular plane coordinates of new points (Table 1), which will enter into adjustment after a preliminary determination, and also orientations and distances between new points and old ones or new ones, calculated from coordinates (Tables 2 and 3, column 4).

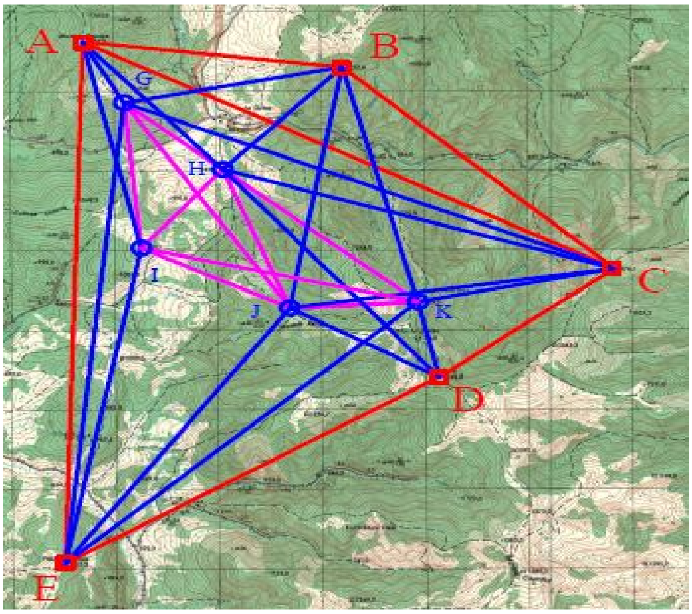

Fig. 5 – The drawing of the geodetic triangulation/trilateration network.

Table 1
Approximated Coordinates of New Points in the Network

Name of point	Plane rectangular coordinates STEREO - 70	
	X, [m]	*Y*, [m]
1	*2*	*1*
A	536,704.451	A
B	536,443.045	B
C	533,968.696	C
D	532,565.108	D

2. Observation equations

At this stage, first it is calculated the mean orientation angle of the station (Table 2, column 7), as the average of individual orientation angles of the station (Table 2, column 6). For that, simple differences $Z^{o}_{ij} = \theta^{o}_{ij} - \alpha^{o}_{ij}$, must be integrated into a formula with multiple queries to adjust the final value in the range [0 - 400^{g}]:

$$\mathrm{IF}(\theta^{o}_{AB} - \alpha^{o}_{AB} < 0,\ \theta^{o}_{AB} - \alpha^{o}_{AB} + 400,\ \theta^{o}_{AB} - \alpha^{o}_{AB}). \qquad (1)$$

Also, for both the directions and distances, the weighting calculation is performed according to the mean square errors in the station (Table 2, column 8 and Table 3, column 6).

Table 2
Calculation of Orientation Angles of Stations

No. of obs.	Station point	Target point	Approximated orientations θ^0_{ij} [g c cc]	Azimuthal directions α^0_{ij} [g c cc]	Orientation angle of the station Z^0_{ij}, [g c cc]	Mean orientation angle of the station Z^0_i [g c cc]	Weights p_{ij}
1	A	B	106.5940	0.0000	106.5940		0.002
2		C	130.8327	24.2391	106.5936	106.5932	0.002
3		H	153.9923	47.3974	106.5949		0.002
4		G	167.8735	61.2839	106.5897		0.002
5		I	184.9771	78.3858	106.5913		0.002
6		E	200.3417	93.7462	106.5955		0.002
7	B	C	147.3994	0.0000	147.3994	147.3970	0.002
8		K	183.1475	35.7495	147.3980		0.002
9		J	209.2418	61.8444	147.3974		0.002
10		H	245.3202	97.9246	147.3956		0.002
11		G	285.4734	138.0784	147.3951		0.002
12		A	306.5940	159.1977	147.3963		0.002
13	C	D	255.3951	0.0000	255.3951	255.3921	0.002
14		K	284.8507	29.4554	255.3953		0.002
15		J	288.6991	33.3071	255.3919		0.002
16		H	318.8701	63.4806	255.3895		0.002
17		G	325.0456	69.6543	255.3913		0.002
18		A	330.8327	75.4407	255.3920		0.002
19		B	347.3994	92.0098	255.3896		0.002
20	D	E	262.1514	0.0000	262.1514	262.1517	0.001
21		J	333.2190	71.0691	262.1498		0.001
22		H	355.6240	93.4760	262.1480		0.001
23		K	385.0571	122.9037	262.1534		0.001
24		C	55.3951	193.2391	262.1561		0.001
25	E	A	0.3417	0.0000	0.3417	0.3423	0.002
26		G	4.9152	4.5694	0.3458		0.002
27		I	10.3688	10.0235	0.3453		0.002
28		J	36.5454	36.2020	0.3434		0.002
29		K	49.8615	49.5230	0.3386		0.002
30		D	62.1514	61.8126	0.3388		0.002
31	G	A	367.8735	0.0000	367.8735	367.8714	0.002
32		B	85.4734	117.6025	367.8709		0.002
33		C	125.0456	157.1736	367.8720		0.002
34		H	144.6916	176.8216	367.8701		0.002
35		J	163.2904	195.4201	367.8703		0.002
36		I	192.8764	225.0060	367.8705		0.002
37		E	204.9152	237.0423	367.8729		0.002
38	H	B	45.3202	0.0000	45.3202	45.3180	0.002
39		C	118.8701	73.5505	45.3196		0.002
40		K	144.6107	99.2927	45.3181		0.002
41		D	155.6240	110.3052	45.3188		0.002
42		J	175.9275	130.6091	45.3184		0.002
43		I	241.5293	196.2105	45.3188		0.002
44		G	344.6916	299.3754	45.3162		0.002
45		A	353.9923	308.6784	45.3139		0.002

Table 2
Calculation of Orientation Angles of Stations (continuation)

No. of obs.	Station point	Target point	Approximated orientations θ^0_{ij} [g c cc]	Azimuthal directions α^0_{ij} [g c cc]	Orientation angle of the station Z^0_{ij} [g c cc]	Mean orientation angle of the station Z^0_i [g c cc]	Weights p_{ij}
46	I	A	384.9771	0.0000	384.9771	384.9747	0.002
47		G	392.8764	7.9019	384.9745		0.002
48		H	41.5293	56.5553	384.9740		0.002
49		K	114.4297	129.4549	384.9748		0.002
50		J	129.4269	144.4516	384.9752		0.002
51		E	210.3688	225.3961	384.9727		0.002
52	J	B	9.241808	0.0000	9.2418	9.2385	0.002
53		C	88.69906	79.4606	9.2385		0.002
54		K	94.72563	85.4873	9.2383		0.002
55		D	133.2189	123.9827	9.2363		0.002
56		E	236.5454	227.3062	9.2392		0.002
57		I	329.4269	320.1895	9.2373		0.002
58		G	363.2904	354.0525	9.2379		0.002
59		H	375.9275	366.6888	9.2387		0.002
60	K	B	383.1475	0.0000	383.1475	383.1479	0.002
61		C	84.85071	101.7037	383.1470		0.002
62		D	185.0571	201.9098	383.1473		0.002
63		E	249.8615	266.7164	383.1451		0.002
64		J	294.7256	311.5763	383.1493		0.002
65		I	314.4297	331.2811	383.1486		0.002
66		H	344.6107	361.4605	383.1502		0.002

Table 3
Calculation of Approximated Elements for Distances

No. of obs.	Station point	Target point	Approximated distances D^*_{ij} [m]	Measured distances D^o_{ij} [m]	Weights p_{ij}
1	*2*	*3*	*4*	*5*	*6*
67	G	H	1271.963	1271.962	1189.06
68		J	3039.278	3039.289	1111.11
69		I	1835.863	1835.830	1189.06
70	H	K	2518.018	2518.020	1111.11
71		J	1857.691	1857.685	1189.06
72		I	1262.171	1262.206	1189.06
73	I	K	2761.512	2761.476	1111.11
74		J	1622.274	1622.276	1189.06
75	J	K	1243.114	1243.134	1189.06

Next, initial formulas for adjusted azimuthal directions are written as differences between the approximated orientations and the mean orientation angle of the station (Table 4, column 5). Also, in this case, simple differences $\alpha_{ij} = \theta^o_{ij} - Z^o_i$, must be integrated into a multiple interrogations formula, for adjusting of the final value in the range [0 – 400g]:

$$\mathrm{IF}(\theta^o_{AB}-Z^o_A<0,\ \theta^o_{AB}-Z^o_A+400,\ \theta^o_{AB}-Z^o_A). \qquad (2)$$

The values of the corrections are obtained by the differences between the values of adjusted azimuthal directions and the approximated ones. (Table 4, column 6). For the directions measured in every station it is imposed an interrogative additional condition, in order to obtain the values expressed in centesimal seconds, by the type:

$$\mathrm{IF}(\alpha_{ij}-\alpha^o_{ij}>300,\ [(\alpha_{ij}-\alpha^o_{ij})-400]\times 10^4,\ [(\alpha_{ij}-\alpha^o_{ij})\times 10^4]). \qquad (3)$$

3. Adjusted coordinates calculation

This calculation step is realised using the *Solver* application. In the dialog box appropriate to the solving parameters is completed the following:

- At the option *Set Objective* it is introduced the reference to the cell from the Excel worksheet, where the sum of the products of weights and squares corrections [pvv] was calculated. Because the adjustment is achieved by applying the principle of least squares, the option where the value of the reference cell leads to minimum is checked.

- At the option *By Changing Variable Cells* are introduced references to the approximated coordinates of the new points, to be subject to the adjustment. Because the minimum condition is sufficient, the box corresponding to restrictions will remain blank.

- It is established the solving method from those three described previously. In this case, the chosen method will be represented by the *GRG Nonlinear* algorithm. After the options of the GRG algorithm are set, where it is checked the option *Central* for the derivative type and the additional general options are set regarding the accuracy, the number of iterations, the running time etc., according to user`s preferences, the application is launched generating the adjusted coordinates for the new points of the triangulation/trilateration network.

Table 4

The Corrections Calculation for Directions and Distances

(after using the Solver application)

No. of obs	Station point	Target point	Weights p_{ij}	Adjusted azimuthal directions α_{ij} (g c cc)	Corrections v_{ij} (cc)	pvv
1	*2*	*3*	*4*	*5*	*6*	*7*
1	A	B	0.002	0.0009	8.6811	0.1165
2		C	0.002	24.2395	4.4290	0.0303
3		H	0.002	47.3992	17.4618	0.4714
4		G	0.002	61.2804	-35.1773	1.9132
5		I	0.002	78.3840	-18.7884	0.5458
6		E	0.002	93.7486	23.3936	0.8461
7	B	C	0.002	0.0025	24.7572	1.1023
8		K	0.002	35.7505	10.2110	0.1875
9		J	0.002	61.8448	4.5346	0.0370
10		H	0.002	97.9232	-13.5426	0.3298
11		G	0.002	138.0764	-19.2022	0.6631
12		A	0.002	159.1971	-6.7581	0.0821
13	C	D	0.002	0.0030	29.9881	1.7240
14		K	0.002	29.4586	32.0800	1.9729
15		J	0.002	33.3069	-1.9364	0.0072
16		H	0.002	63.4780	-25.8627	1.2823
17		G	0.002	69.6535	-8.1688	0.1279
18		A	0.002	75.4406	-1.1498	0.0025
19		B	0.002	92.0073	-24.9504	1.1934
20	D	E	0.001	399.9997	-3.1501	0.0148
21		J	0.001	71.0672	-18.8731	0.5299
22		H	0.001	93.4722	-37.7386	2.1189
23		K	0.001	122.9054	16.5764	0.4088
24		C	0.001	193.2434	43.1854	2.7746
25	E	A	0.002	399.9995	-5.2552	0.0562
26		G	0.002	4.5729	35.4340	2.5567
27		I	0.002	10.0265	29.9554	1.8272
28		J	0.002	36.2031	11.5344	0.2709
29		K	0.002	49.5193	-37.1897	2.8163
30		D	0.002	61.8091	-34.4790	2.4207
31	G	A	0.002	0.0021	20.9797	0.6956
32		B	0.002	117.6020	-5.0133	0.0397
33		C	0.002	157.1742	5.1103	0.0413
34		H	0.002	176.8202	-13.9216	0.3063
35		J	0.002	195.4190	-11.3407	0.2033
36		I	0.002	225.0050	-9.8814	0.1543
37		E	0.002	237.0438	14.0670	0.3127
38	H	B	0.002	0.0022	21.8809	0.7938
39		C	0.002	73.5521	16.0585	0.4275
40		K	0.002	99.2927	0.6857	0.0008
41		D	0.002	110.3060	7.9606	0.1051
42		J	0.002	130.6095	3.5665	0.0211
43		I	0.002	196.2113	8.1752	0.1108
44		G	0.002	299.3736	-17.6870	0.5187
45		A	0.002	308.6743	-40.6403	2.7384
46	I	A	0.002	0.0024	24.0403	0.9247
47		G	0.002	7.9017	-2.2221	0.0079
48		H	0.002	56.5546	-7.2520	0.0841
49		K	0.002	129.4549	0.3177	0.0002
50		J	0.002	144.4521	4.9796	0.0397

Table 4
The Corrections Calculation for Directions and Distances (continued)

No. of obs.	Station point	Target point	Weights p_{ij}	Adjusted azimuthal directions α_{ij} (g c cc)	Corrections v_{ij} (cc)	pvv
51		E	0.002	225.3941	-19.8635	0.6313
52	J	B	0.002	0.0033	32.9731	1.8091
53		C	0.002	79.4606	-0.3335	0.0002
54		K	0.002	85.4871	-1.9094	0.0061
55		D	0.002	123.9804	-21.8254	0.7926
56		E	0.002	227.3069	6.8862	0.0789
57		I	0.002	320.1883	-11.5780	0.2231
58		G	0.002	354.0519	-5.7329	0.0547
59		H	0.002	366.6889	1.5199	0.0038
60	K	B	0.002	399.9996	-3.6666	0.0203
61		C	0.002	101.7028	-8.3246	0.1048
62		D	0.002	201.9093	-5.8527	0.0518
63		E	0.002	266.7137	-27.3639	1.1319
64		J	0.002	311.5778	14.4164	0.3142
65		I	0.002	331.2818	7.1845	0.0780
66		H	0.002	361.4629	23.6069	0.8424
No. of obs.	Station point	Target point	Weights p_{ij}	Adjusted distances D_{ij} [m]	Corrections v_{ij} (m)	pvv
67	G	H	1189.06	1271.963127	0.00113	0.0015
68		J	1111.11	3039.27762	-0.01138	0.1439
69		I	1189.06	1835.863379	0.03338	1.3248
70	H	K	1111.11	2518.017594	-0.00241	0.0064
71		J	1189.06	1857.690599	0.0056	0.0373
72		I	1189.06	1262.171039	-0.03496	1.4533
73	I	K	1111.11	2761.511837	0.03584	1.427
74		J	1189.06	1622.273772	-0.00223	0.0059
75	J	K	1189.06	1243.114134	-0.01987	0.4693
					[pvv]	**46.9690**

The results obtained for the adjusted coordinates using Solver application are identical up to millimetre precision with the results from the classic method using matrices (Table 5).

Table 5
Adjusted Coordinates of the Network Points

Name of the point	Adjusted absolute coordinates	
	X, [m]	*Y*, [m]
G	535,955.171	588,119.204
H	535,133.792	589,090.403
I	534,130.789	588,324.204
J	533,407.335	589,776.232
K	533,510.209	591,015.082

Adjustment check is done by the differences between orientations and distances calculated based on the functional model and the orientations of directions, respectively the distances, calculated using adjusted coordinates of the new points and the coordinates of the old points. The comparison between the two series of values shows the equality of the quantities, therefore the correctness of the adjustment computation.

4. The Adjustment of a Geometric Levelling Network Using Microsoft Excel Solver Application

In the geometric levelling networks, geodetic observations consist in measurement of height differences of the benchmarks situated along the levelling lines, which are then reduced in a certain heights system. It is considered a constrained geometric levelling network formed of two control benchmarks (A, B) of known height and twelve new ones (1, 2,..., 12), between which develop 22 geometric levelling sections (Fig. 6).
For adjusting the constrained geometric levelling network using *Solver* application, the problem will be structured with conditional weighted measurements functional model, following the next steps (Nistor, 1998).

4.1. The Establishment of the Number of Independent Condition Equations, Necessary and Sufficient to Adjust The Network

If it is considered that P is the number of the polygons and N is the number of the benchmarks with known heights, belonging to the network of higher order, the number of independent conditional equations, necessary and sufficient to adjust the network is given by the relation: $R = P + (N - 1)$. For the studied network, the number of independent conditional equations is: $R = 9 + + (2 - 1) = 10$.

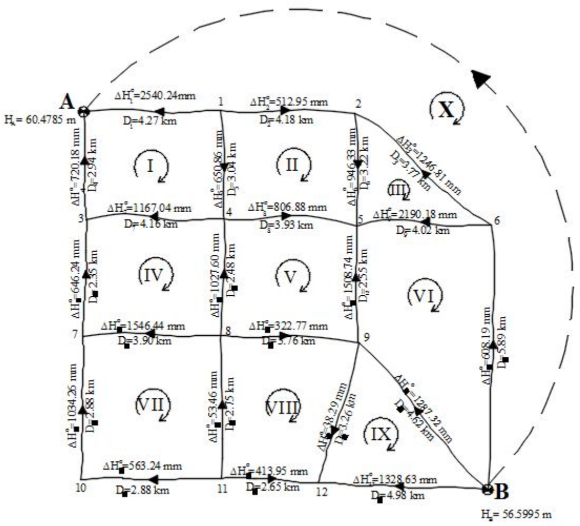

Fig. 6 – The sketch of geometric levelling network.

4.2. The Equations of Condition

For the writing of the equation of condition from first category, which are deriving from the interior conditions, are used the levelling polygons I, II,…, IX. The equations of condition, proper for height differences, will be by the following type:

$$\begin{aligned}
&1.\quad -\Delta H_1 + \Delta H_5 + \Delta H_7 + \Delta H_4 = 0;\\
&2.\quad \Delta H_2 + \Delta H_6 - \Delta H_8 - \Delta H_5 = 0;\\
&3.\quad -\Delta H_3 + \Delta H_9 - \Delta H_6 = 0;\\
&4.\quad -\Delta H_7 - \Delta H_{11} + \Delta H_{14} + \Delta H_{10} = 0;\\
&5.\quad \Delta H_8 - \Delta H_{12} - \Delta H_{15} + \Delta H_{11} = 0;\\
&6.\quad -\Delta H_9 - \Delta H_{13} + \Delta H_{16} + \Delta H_{12} = 0;\\
&7.\quad -\Delta H_{14} - \Delta H_{18} + \Delta H_{20} + \Delta H_{17} = 0;\\
&8.\quad \Delta H_{15} + \Delta H_{19} - \Delta H_{21} + \Delta H_{18} = 0;\\
&9.\quad -\Delta H_{16} + \Delta H_{22} - \Delta H_{19} = 0.
\end{aligned} \tag{4}$$

A new closed polygon is formed, with crossing route in the same direction. The 10th equation of condition, named constrained equation or height accord, will be written in the following form:

$$10.\quad -\Delta H_{AB} + \Delta H_1 - \Delta H_2 + \Delta H_3 + \Delta H_{13} = 0. \tag{5}$$

4.3. The Solving Model Using Microsoft Excel Solver

In Table 6 the situation before the optimization is presented, where:

a) the weights are calculated inversely proportional with the length of the section (column 5);

b) the initial corrections are considered null, their values being determined subsequent, automatically, after the run of the application (column 6);

c) the formulas for the multiplication between weights and correction squares are established, this column being modified after the running of the application (column 8);

d) the formulas for the adjusted height differences are introduced, as a sum between measured height differences (ΔH^0_i) and the size of corrections (v_i) (column 7);

e) in the last cell of column 8 it is written the formula for the sum of products between weights and square corrections.

Table 6
Corrections Calculation for the Height Differences

No. of section	Section	Mean measured height differences ΔH^0_i [mm]	Lengths of sections D_i [km]	Weights p_i	Corrections v_i [mm]	Adjusted height differences ΔH_i [mm]	pvv
1	2	3	4	5	6	7	8
1	1-A	2,540.24	4.27	0.2341	0	2,540.24	0.000
2	1-2	512.95	4.18	0.2392	0	512.95	0.000
3	6-2	1,246.81	3.77	0.2652	0	1,246.81	0.000
4	3-A	720.18	2.94	0.3401	0	720.18	0.00
5	1-4	650.86	3.04	0.3289	0	650.86	0.000
6	2-5	946.33	3.22	0.3105	0	946.33	0.000
7	4-3	1,167.04	4.16	0.2403	0	1,167.04	0.000
8	4-5	806.88	3.93	0.2544	0	806.88	0.000
9	6-5	2,190.18	4.02	0.2487	0	2,190.18	0.000
10	7-3	646.24	2.35	0.4255	0	646.24	0.000
11	8-4	1,027.6	2.48	0.4032	0	1,027.6	0.000
12	9-5	1,508.74	2.55	0.3921	0	1,508.74	0.000
13	B-6	608.19	5.89	0.1697	0	608.19	0.000
14	8-7	1,546.44	3.9	0.2564	0	1,546.44	0.000
15	8-9	322.77	3.76	0.2659	0	322.77	0.000
16	B-9	1,287.32	4.62	0.2164	0	1,287.32	0.000
17	10-7	1,034.26	2.88	0.3472	0	1,034.26	0.000
18	11-8	53.46	2.75	0.3636	0	53.46	0.000
19	9-12	38.29	3.26	0.3067	0	38.29	0.000
20	11-10	563.24	2.88	0.3472	0	563.24	0.000
21	11-12	413.95	2.65	0.3773	0	413.95	0.000
22	B-12	1,328.63	4.98	0.2008	0	1,328.63	0.000
						[pvv]	**0.000**

When running *Solver* application, the parameters of the dialog box are completed in the following way:

i) in the box *Set Objective* it is introduced a reference for the sum of products between weights and the square corrections, over which the minimum condition is applied;

ii) in the box *By Changing Variable Cells* it is selected the corrections column, with previous values of zero (*Table 6*, *Column 6*);

iii) regarding restrictions, it is necessary that the results obtained from the equations of conditions (1,..., 10) should equal zero. (*Table 7, Columns 1-3*);

iv) the solving method and the afferent options are chosen as in the previous case.

Table 7
Conditions of Constraint in the Levelling Network

Calculated conditions [mm]	Constrained conditions [mm]	Conditions after adjustment [mm]	Number of the benchmark	Adjusted heights [m]
1	*2*	*3*	*4*	*5*
-2.16	0	0.00	1	57.93946
1.54	0	0.00	2	58.45235
-2.96	0	0.00	3	59.75794
-1.96	0	0.00	4	58.59121
2.97	0	0.00	5	59.39760
-2.31	0	0.00	6	57.20676
-2.40	0	0.00	7	59.11121
0.57	0	0.00	8	57.56484
3.02	0	0.00	9	57.88811
3.29	0	0.00	10	58.07630
			11	57.51242
			12	57.92678

The results obtained after the adjustment using *Solver* application are shown in Table 7, regarding the results of the equations of conditions (column 3) the heights obtained from adjusted height differences (column 5) and in the Table 8 (column 7) regarding adjusted height differences. These are identical by the precision of ±0.01 mm with those from the classic method using matrices.

Table 8
Adjusted Elements in Solver Application

No. of section	Section	Mean measured height differences ΔH^0_i, [mm]	Lengths of sections D_i, [km]	Weights p_i	Corrections v_i, [mm]	Adjusted height differences ΔH_i, [mm]	pvv
1	2	3	4	5	6	7	8
1	1-A	2540.24	4.27	0.2341	-1.19	2539.04	0.3364
2	1-2	512.95	4.18	0.2392	-0.05	512.90	0.0007
3	6-2	1246.81	3.77	0.2652	-1.21	1245.59	0.3924
4	3-A	720.18	2.94	0.3401	0.38	720.56	0.0502
5	1-4	650.86	3.04	0.3289	0.89	651.75	0.2625
6	2-5	946.33	3.22	0.3105	-1.08	945.25	0.3630
7	4-3	1167.04	4.16	0.2403	-0.31	1166.72	0.0240
8	4-5	806.88	3.93	0.2544	-0.48	806.39	0.0609
9	6-5	2190.18	4.02	0.2487	0.66	2190.84	0.1091
10	7-3	646.24	2.35	0.4255	0.48	646.73	0.1003
11	8-4	1027.6	2.48	0.4032	-1.22	1026.37	0.6060
12	9-5	1508.74	2.55	0.3921	0.75	1509.49	0.2228
13	B-6	608.19	5.89	0.1697	-0.92	607.26	0.1468
14	8-7	1546.44	3.9	0.2564	-0.06	1546.37	0.0011
15	8-9	322.77	3.76	0.2659	0.50	323.27	0.0667
16	B-9	1287.32	4.62	0.2164	1.28	1288.61	0.3595
17	10-7	1034.26	2.88	0.3472	0.64	1034.91	0.1446
18	11-8	53.46	2.75	0.3636	-1.04	52.42	0.3943
19	9-12	38.29	3.26	0.3067	0.38	38.67	0.0444
20	11-10	563.24	2.88	0.3472	0.64	563.89	0.1446
21	11-12	413.95	2.65	0.3773	0.40	414.36	0.0634
22	B-12	1328.63	4.98	0.2008	-1.35	1327.28	0.3663
						[pvv]	**4.2608**

5. Conclusions

Comparing the results of the adjustment using *Solver* application and those obtained from the classic method using matrices, in the case of a triangulation - trilateration network, and also a levelling network, it is shown their equality, on the specific level of precision.
It is worth mentioning some of the advantages of using Solver application in geodetic adjustment (Tasçi, 2009):

a) it is not necessary for the user to possess advanced knowledge about applying the least squares method, but they need to have elementary notions about adjustment of geodetic measurements, by indirect observations or conditional observations method;

b) the solution is easily obtained when all the conditions are properly completed;

c) the application offers a friendly interface and simple ways of setting parameters and establishing restrictions;

d) in some cases, the formulas must integrate multiple queries to adjust the final values of certain variables;

e) the standard application does not impose supplementary costs, because it is included in Microsoft Office package.

Among the disadvantages, it can be observed the absence of some computed elements that are necessary to evaluate the precision of the results, for example the covariance matrix of the unknown parameters (Hashimi., 2004).

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APLICAŢII ALE MICROSOFT EXCEL - SOLVER LA COMPENSAREA REŢELELOR GEODEZICE PLANIMETRICE ŞI DE NIVELMENT

(Rezumat)

În cazul prelucrării riguroase a măsurătorilor geodezice, pentru aplicarea principiului celor mai mici pătrate, este necesar să se rezolve un sistem de ecuaţii

liniarizate, care necesită cunoaşterea coeficienților necunoscutelor sub forma derivatelor parțiale ale unor funcții specifice. Fără a mai fi nevoie ca operatorul să efectueze această etapă de calcul, aplicația *Solver* determină direct soluția optimă, care respectă condiția de minim impusă. În acest caz, se prezintă modul de rezolvare a unor probleme de compensare structurate după metoda observațiilor indirecte pentru o rețea de triangulație – trilaterație geodezică şi după metoda observațiilor condiționate pentru o rețea de nivelment geometric. În final, se compară rezultatele obținute față de cele cunoscute din aplicarea metodelor clasice, sugerând cele mai adecvate opțiuni pentru utilizarea interfeței *Solver*.