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The Number of Set Ups in Lines as Weights in the Precise Levelling

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Abstract. The main method for monitoring of vertical displacements of engineering constructions and estimation of deformation processes is the precise geometric levelling. This method is also essential for defining the state height systems, which are the base of any vertical engineering network. An extremely important factor about the final accuracy of a geometric levelling network is not only the accuracy of measurements, but also the choice of the weights, applied in its adjustment. The recent specification for the precise levelling in Bulgaria allows two types of weights. The first ones are the classical weights, which are inversely proportional to the lengths of levelling lines L, in the form $w = 1/L$. The second type of weights are inversely proportional to the number of set ups in the lines n, i.e. $w = 1/n$. The purpose of the current research is to show that there is not significant difference in the results, which would be produced by both types of weights, especially for the territory of Bulgaria. In order to prove this fact, we adjusted the network of the Third Levelling Bulgaria by both types of weights. The differences between the standard errors of the adjusted heights of the identical benchmarks in the network, produced by adjustments with both weights, vary in the range ±0.5 mm. The differences between the adjusted heights of the same benchmarks in the network, obtained in both variants of adjustment of the network, vary from -1.1 mm to 1.3 mm. The distributions of the last differences approximate normal distribution with the expectation $\mu = 0.12$ mm and standard deviation $\sigma = 0.61$ mm. These results can be explained by the high correlation between the length of the levelling lines and the number of the set ups. We estimated that the coefficient of correlation between L and n in the case of the Third Levelling of Bulgaria is equal to 0.976. The general conclusion is that we cannot expect any significant increase of the adjustment accuracy of a levelling network, if we change the weights $w = 1/L$ with the weights $w = 1/n$. This conclusion is especially valid for networks developed through flat areas, where the most of lengths of the sights are approximately equal.

Keywords: analogue learning, digital study courses, teaching methodology, higher education

INTRODUCTION

The precise geometric levelling is the main method for solving many scientific and engineering tasks related to the recent vertical movements of the Earth's crust [7], the changes in slopes and levels of the oceans and seas, defining of continental and / or state reference height systems [11, 13], monitoring of engineering construction [2], etc. An extremely important factor about the final accuracy of a geometric levelling network is not only the accuracy of measurements, but also the choice of the weights, applied in its adjustment. The recent specification for the precise levelling in Bulgaria [8], which impotently extends and modernizes the old one [12], allows two types of weights. The first ones are the classical weights, which are inversely proportional to the lengths of levelling lines *L* and defined by equation (1).

$$w = 1/L \tag{1}$$

The second type of weights are inversely proportional to the number of set ups in levelling lines *n* and given by equation (2).

$$w = 1/n \tag{2}$$

The use of the weights (1) is recommended for geometric levelling networks established on flat areas. The weights (2) are supposed to be appropriate for precise levelling networks in mountain territories [10]. The relationship between the length of a levelling line *L* and the number of set ups *n* in the line, is the length of the sight, i.e., the distance from the level to the backward and the forward staffs *l*. This relationship can be expressed by equation (3).

$$L = n.l \tag{3}$$

According to the old Bulgarian instruction [8], the length of the sight have to be $l \leq 40$ m. Therefore, if a levelling line passes through a flat area, the minimum number of set ups should be 14. Analyzing the Third campaign levelling data of Bulgaria [1], it can be seen that the number of set ups in the lines varies from 14 to 28. The average and the median values are 18 set ups per 1 km levelling, which corresponds to the average length of sight $l \approx 28$ m. This value is close to the maximum allowed by the new instruction [8] distance of $l \leq 30$ m. The ratio between the minimal average set ups and the maximum average setups in the Third Levelling of Bulgaria is 28 / 14 = 2. Such a small coefficient supposes a high correlation between the quantities *L* and *n*.

Based on the above logic, the main purpose of the current research is to show that there is not significant difference in the results, which would be produced by both types of weights (1) and (2), especially for the territory of Bulgaria.

MATERIAL AND METHODS

In the current research, we use the data of the Third Levelling of Bulgaria /1975-1984/ [1]. We adjusted the network below by parametric least squares method in two variants. In the first variant and the second variant, we used weights (1) and (2), respectively. Our datum point in both variants will be the FBM 28 in Varna.

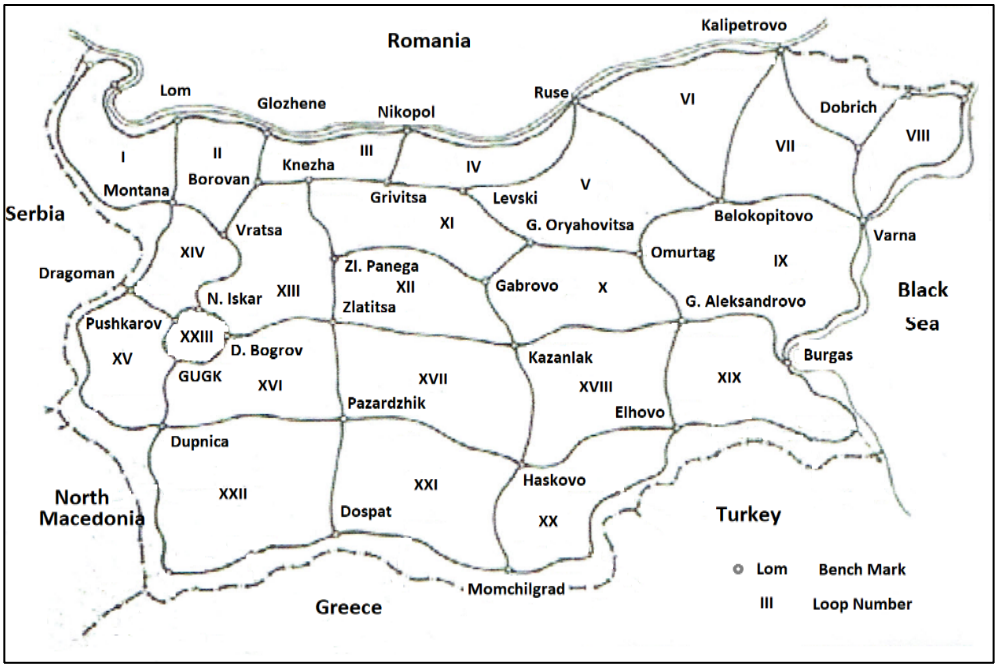

FIGURE 1. The Third Precise Levelling Network of Bulgaria /1975-1984/.

RESULTS

Table 1, Table 2 and Figure 2 below give the results, produced by both adjustment variants.

TABLE 1. The standard errors of the adjusted heights of the nodal benchmarks in the adjustments with weights *w=1/L* and *w=1/n*

Benchmark	Distance from FBM 28 (km)	Weights		Benchmark	Distance from FBM 28 (km)	Weights	
		w=1 / L	*W = 1 / n*			*w=1 / L*	*W = 1 / n*
Dobric	51.7	7.2	7.2	Zl. Panega	461.8	14.2	14.1
Belokopitovo	110.8	9.4	8.9	Zlatica	493.3	14.2	14.2
Kalipetrovo	149.4	10.3	9.8	Borovan	497.0	14.5	14.2
Burgas	151.9	11.5	11.5	Glozhene	497.7	14.9	14.7
Omurtag	171.3	11.2	10.8	Vratsa	531.2	15.0	14.8
Ruse	222.6	11.7	11.3	Pazardjik	549.9	15.0	14.9
G. Aleksandrovo	228.7	11.7	11.7	Momchilgrad	551.9	15.6	16.1
G. Oryahovitsa	256.0	12.7	12.8	Lom	557.8	15.9	15.6
Elhovo	294.1	13.3	13.5	D. Bogrov	566.2	15.1	15.1
Gabrovo	320.8	13.4	13.7	Montana	574.9	15.5	15.4
Levski	348.0	13.0	12.9	N. Iskar	584.0	15.2	15.1
Kazanluk	362.8	13.3	13.4	GUGK	596.6	15.3	15.2
Nikopol	366.8	13.8	13.6	Pushkarov	597.9	15.2	15.2
Grivitsa	393.9	13.4	13.3	Dragoman	636.2	15.8	15.7
Haskovo	416.1	14.2	14.3	Dupnitsa	658.5	15.8	15.8
Knezha	460.4	14.0	13.8	Dospat	750.1	16.5	16.9

TABLE 2. t-Test: Paired Two Sample for Means of the standard errors of the adjusted heights of the nodal benchmarks, obtained by both adjustments with weights *w=1/L* and *w=1/n,* respectively.

Statistics	w=1/L	w=1/n
Mean	13.68	13.61
Median	14.21	14.17
Variance	4.40	4.81
Observations	32	32
Pearson Correlation	0.995	
Hypothesized Mean Difference	0	
df	31	
t Stat	1.712	
P(T<=t) two-tail	0.097	
t Critical two-tail	2.040	

According to the results presented by Table 1, Table 2 and Figure 2, the results produced by both adjustments with weights *w=1/L* and *w=1/n* are almost identical.

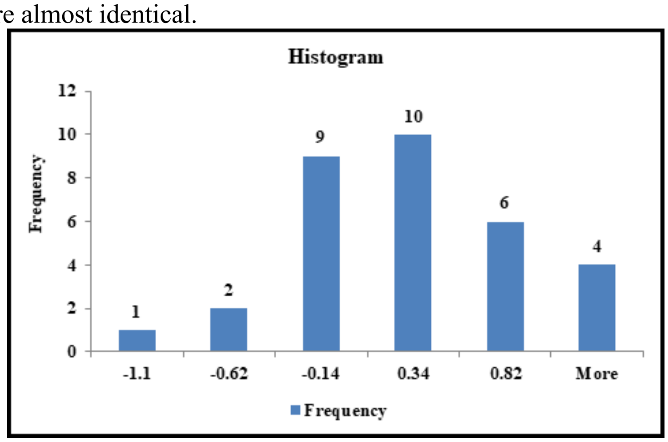

FIGURE 2. Histogram of the differences in mm between the standard errors of the adjusted heights of the nodal benchmarks in the adjustments with weights *w=1/L* and *w=1/n.*

DISCUSSION

The main objective of the current research was to show that there is not significant difference in the results, which will be obtained by an adjustment of a precise levelling network with weights (1) and (2), especially for the territory of Bulgaria.

According to Table 1, the absolute values of the differences between the standard errors of the adjusted nodal benchmarks in the precise levelling network of Bulgaria – III campaign are up to 0.5 mm. Their average is 0.1 mm. According to Table 2, we cannot reject at 95% significance level the hypothesis that the mean of the standard errors based on the weights *w=1/L* is equal to the mean of the standard errors based on the weights *w=1/n.* In addition, according to Figure 2, the differences between the adjusted heights of the nodal benchmarks by the use of the weights *w=1/L* and *w=1/n* vary in the range from -1.1 mm to 1.3 mm. As can be seen from Figure 2, the distribution of these differences approximates Normal Distribution with parameters for expectation μ = 0.1 mm and standard deviation σ = 0.6 mm. Thus, there is neither statistical support nor practical evidence for any difference of the performance between both types of weights *w=1/L* and *w=1/n.* As a result, the strong correlation between the standard errors of the adjusted heights of the nodal benchmarks, which is typical for the weights $w=1/L$, is available in the results yielded by the adjustment with weights $w=1/n$.

The reason for all these facts is the great correlation between L and n, which we calculate to be $R_{L,n} = 0.976$. Figure 3 illustrates this strong, almost functional, relationship.

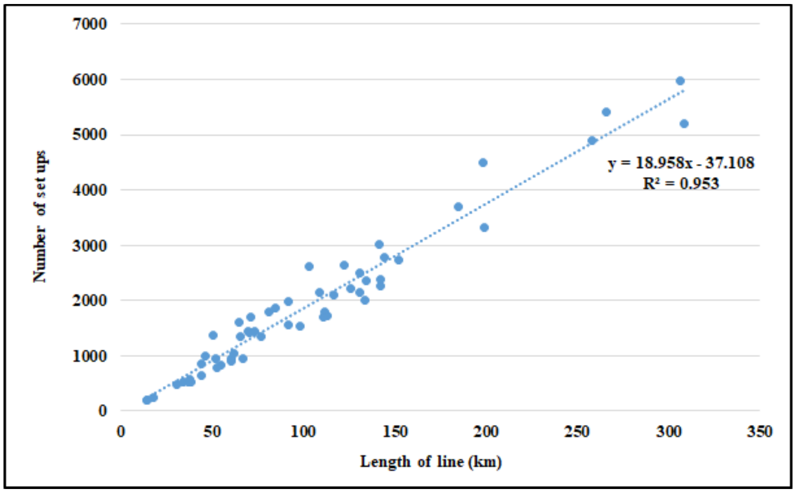

FIGURE 3. Relationship between the length of levelling lines and the number of the set ups along line in the Third Levelling of Bulgaria /1975-1984/

CONCLUSION

The general conclusion is that we cannot expect any significant increase of the adjustment accuracy of a levelling network, if we change the weights $w = 1/L$ with the weights $w = 1/n$. This conclusion is especially valid for networks developed through flat areas, where the most of lengths of the sights are approximately equal. The prescriptions of [8] should be extended by including different types of weights. The appropriate ones are based on the measured height differences in levelling lines [4, 5]. In addition, the whole methodology of the adjustment of the precise levelling networks given by [8] should be revised [3] and modernized by the recent findings [6]. Taking into account and the criticism of other researches [9, among others], it is time for a new instruction for establishment, measurement and maintenance of the precise levelling networks in Bulgaria.

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