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REFRACTION CORRECTION APPLIED TO PRECISE LEVELING OBSERVATIONS

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ABSTRACT

Some problems have been investigated when applying a correction to reduce the effect of vertical refraction when precise leveling is performed. The obtained results show that the correction has to be calculated for each setup. It is not eliminated when passing the same positive and negative differences of elevation. Inaccurately measured temperatures have a great negative impact. They can cause incorrectly calculated correction and hence wrong results. For this reason it is crucial that temperatures be measured simultaneously with the leveling by aspiration thermometer with an accuracy ± 0.1 ° C. It is highly recommended to do experimental research and to adopt appropriate for Bulgaria model for taking into account the influence of vertical refraction.

INTRODUCTION

Atmospheric refraction is the deflection of light or other electromagnetic waves from the straight line due to the change in air density as a function of the height above the ground. Refraction is due to a reduction in the speed of light as the air layer density increases. As the geodetic measurements are carried out near the ground surface, the results are significantly influenced from the ground atmosphere. In geodetic leveling, the horizontal line of sight passes through different isothermal layers of air (fig.1). This leads to an error in read of fore and back rods. The error caused by refraction is generally considered to be a significant systematic error in the leveling measurements. In the far 1937, long before refraction was widely accepted as a major source of error, Professor T. J. Kukkamaki of the Finnish Geodetic Institute investigated this phenomenon and develop a mathematical model for correcting (reducing) its impact. He estimated a correction that is proportional to the difference in the measured two temperatures of air at heights of 0.5 m and 2.5 m. Initially only a few countries apply this correction, but now when it is known that it is necessary, the correction is widely used, especially in countries located in the middle and lower latitudes.

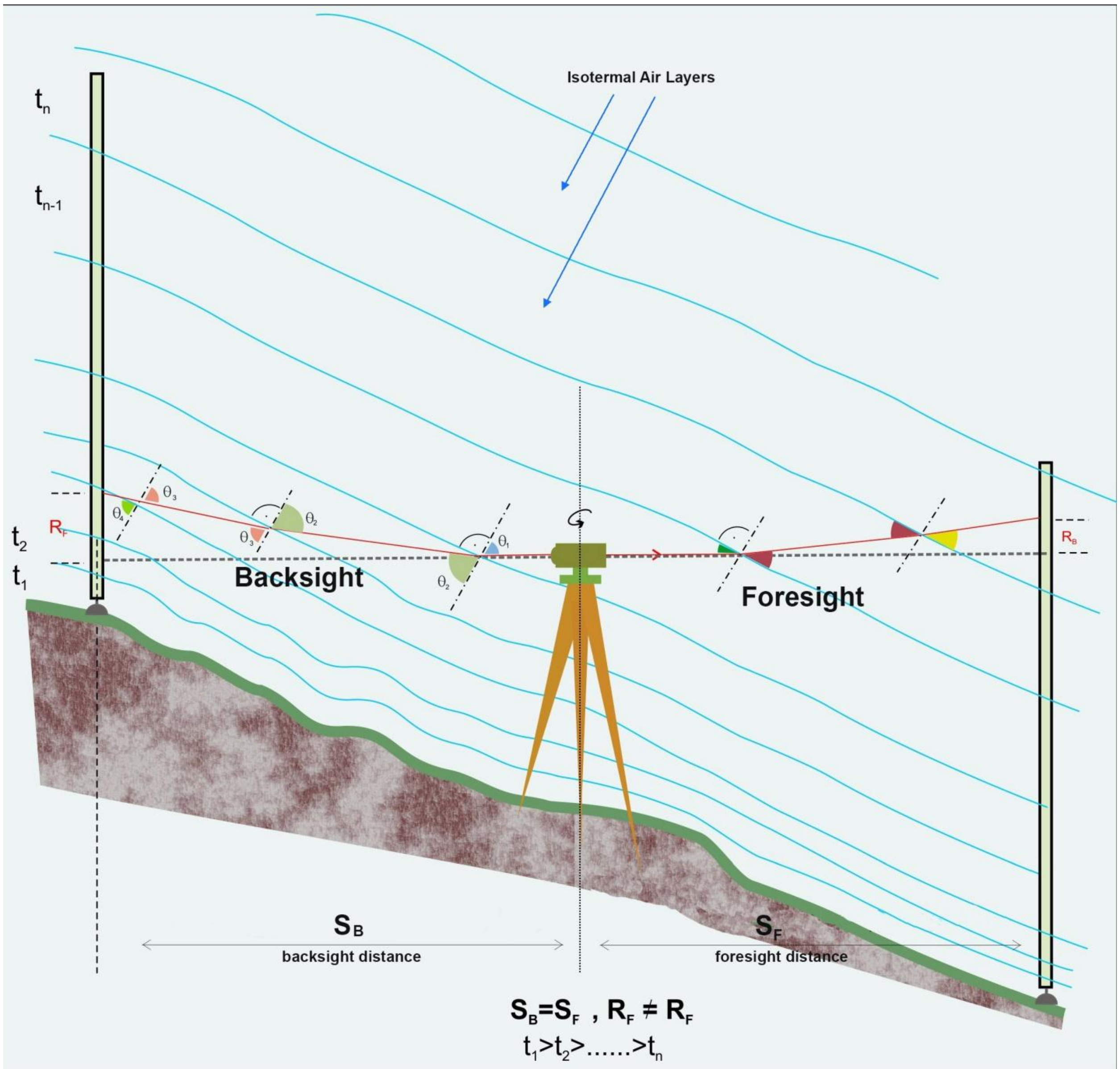

Fig 1 Refraction

THEORETICAL MODEL

The refraction correction for geodetic leveling must be applied to each single set-up (Kukkamaki 1939) and is given by:

$$R = -2 \times 10^{-6} \alpha (S/50)^2 \Delta t \Delta h, \text{ [m]}. \quad [1]$$

Where:

S is the average value of the distances to rods (in meters),

$\Delta t = t_1 - t_2$ is the temperature difference (°C), calculated from the measured temperatures at two heights, t_1 – at a height of 2.5 m и t_2 – at a height of 0.5 m.

Δh measured difference of elevation in set-up (in meters);

α - a pre-determined coefficient. In a numerous of studies it's value is accepted as α = 70. (Hytonen, 1967, NOAA 1981).

The temperature distribution model in the ground air layer is given by:

$$T = a + bz^c \quad [2]$$

Where:

T – temperature (°C) at a height - **z** above the ground surface; ***a***, ***b*** и ***c*** – a, b and c are constants for any instant and vary with time.

The temperature model [2] is based on the following assumptions:

1. The refraction coefficient of air depends mainly on temperature since the effect of humidity is negligibly small for optical propagation.
2. Isothermal surfaces are parallel to the ground.
3. The terrain slope is uniform in a single set-up of the instrument.

Refraction correction based on direct measurement of temperature gradient

The coefficient α [1] is given by:

$$\alpha = \frac{5.95}{z_3^c - z_1^c}\left[\frac{1}{c+1}\left(L_1^{c+1} - L_2^{c+1}\right) - h_i(L_1 - L_2)\right] \quad [3]$$

Where:

Z_3 и Z_1 are heights of the measurement of air temperature (upper and lower); L_1 и L_2 are the heights of the line of sight on the fore and back rods, respectively, h_i is the height of the instrument, and **c** is an exponent [2].

c can be easily computed using three temperature sensors at different heights $\mathbf{z_1}$, $\mathbf{z_2}$, $\mathbf{z_3}$, arranged such that $\frac{z_1}{z_2} = \frac{z_2}{z_3}$.

For each measured temperature are drawn three equations of the type of [3], and through the transformations the estimation of exponent **c** required to obtain the coefficient α [1],[2] is reached:

$$c = \ln\left(\frac{\Delta t_2}{\Delta t_1}\right) / \ln\left(\frac{z_2}{z_1}\right). \qquad [4]$$

The temperature difference Δt in [1] is calculated as a difference between the temperatures measured at heights $\mathbf{z_3}$ and $\mathbf{z_1}$.

Due to the large air temperature fluctuations, direct temperature gradient determination should be performed at single set-up at the same time as the levelling measurements.

Refraction correction based on predicted temperature gradient

This method of correction is approximate and is used in cases where there are no temperature differences measured during the geodetic leveling. The correction must be applied to the difference of elevation for the section, with average line of sight.

$$R = -2 \times 10^{-6} \alpha (S/(2n)50)^2 \Delta t \Delta h w.\ [\mathrm{m}]. \qquad [5]$$

Where: n is number of setups in section, S – section length, w – weather factor, Δt predicted temperature difference. This method is applicable when there is a temperature model of the ground air layer from which the temperature differences are derived directly.

DARA PROCESSING

For the purpose of this study, the level measurements provided by Geodesy, Cartography and Cadastre Agency were used. The measurements were made with a precise digital level Sokkia SDL 1X with couple invar rods. Simultaneously with the leveling, the air temperatures were measured in each set-up at heights of 0.5 m, 1.5 m and 2.5 m. Digital thermometers are used, the sensors are attached to the back of the rods and are protected from direct sunlight.

Leveling book for one leveling distance is shown. The refraction correction is calculated for each set-up (Table 1, column 8) and is aggregated for the whole distance. The temperature differences (Table 2, column 6) are calculated with the average values of the measured temperatures of the two rods for heights of 2.5m and 0.5m.

L E V E L I N G   B O O K

Leveling line: № 47 Kazanlak - № 86 Haskovo

Leveling distance: **KNT** **NR1**

Date: 20 may 2016 Observer: ……………………

Beginning: 11h 08 m Instrument ……………………

End: 11 h 40 m № ……………………

Direction of leveling: west - east Rod № 1: 67147

Atmospheric conditions: Rod № 2: 67148

Temperatures:							Lcp	k
Beginning	Middle	End	avg. Temp.	t'	t^2	Tет	Rod. m.	
21.2	22.2	23.7	22.4	22.2	21.8	20.6	999.9923	0.0000020

№	Dist. [m]	reads: level 1, back 1 / fore 2	reads: level 2, back 1 / fore 2	Diff. of elevation (m): level 1	Diff. of elevation (m): level 2	R (m)	diff. (mm)	превиш. (avg 1,2) m)	amount Diff. of elevation. (m)
1	2	3	4	5	6	7	8	9	10
KNT	29.971	0.62145	0.62148						
1	28.536	1.15687	1.15681	-0.53542	-0.53533	**-0.00002**	-0.09	-0.53538	-0.53538
1	20.072	1.33548	1.33543						
2	23.107	1.52165	1.52162	-0.18617	-0.18619	**0.00000**	0.02	-0.18618	-0.72156
2	28.525	1.50684	1.50690						
3	29.343	1.21576	1.21577	0.29108	0.29113	**-0.00001**	-0.05	0.29111	-0.43045
3	28.382	1.51010	1.51014						
4	29.018	1.36234	1.36237	0.14776	0.14777	**0.00000**	-0.01	0.14777	-0.28269
4	28.212	1.54058	1.54063						
5	28.962	1.39294	1.39288	0.14764	0.14775	**0.00000**	-0.11	0.14770	-0.13499
5	28.202	1.34136	1.34131						
6	29.850	1.38174	1.38173	-0.04038	-0.04042	**0.00000**	0.04	-0.04040	-0.17539
6	28.882	1.48811	1.48814						
7	29.476	1.19509	1.19514	0.29302	0.29300	**0.00001**	0.02	0.29301	0.11762
7	28.100	1.49773	1.49775						
8	28.627	1.29759	1.29761	0.20014	0.20014	**0.00001**	0.00	0.20014	0.31776
8	29.566	1.69603	1.69611						
9	29.462	1.56155	1.56153	0.13448	0.13458	**0.00000**	-0.10	0.13453	0.45229
9	23.377	1.62204	1.62208						
NR1	20.755	0.74426	0.74425	0.87778	0.87783	**0.00003**	-0.05	0.87781	1.33010
S[km]	0.55	SF [m]	12.83	ΔH1 [m]	ΔH2 [m]	**R [m]**	d [mm]		
				1.32993	**1.33026**	**0.00003**	**-0.33**		

Tabl.1 Leveling book

METEOROLOGICAL BOOK					
Leveling distance			KNT	NR1	
Date:	20 may 2016	11:08:46			
Set-up №	Rod	Height of measure			avg. diff.
	back	0.5 m	1.5 m	2.5 m	Δt
	fore	t^oC			
1	2	3	4	5	6
1	Rod №1	22.6	23.6	21.3	-0.8
	Rod № 2	19.6	20.4	19.4	
2	Rod №2	19.4	20.4	19.7	-0.2
	Rod №1	22.3	22.3	21.6	
3	Rod №1	22.3	22.5	21.1	-0.5
	Rod № 2	20.3	21.2	20.5	
4	Rod №2	21.2	22.4	20.6	-0.1
	Rod №1	22.4	22.7	22.7	
5	Rod №1	22.5	23.5	22.3	-0.2
	Rod № 2	21.3	22.5	21.1	
6	Rod №2	21.6	22.5	21.4	-0.3
	Rod №1	21.7	22.4	21.4	
7	Rod №1	22.3	22.4	21.5	-0.4
	Rod № 2	21.4	22.4	21.4	
8	Rod №2	22.2	22.6	21.4	-1.1
	Rod №1	22.5	22.3	21.2	
9	Rod №1	23.4	23.4	22.4	-0.6
	Rod № 2	22.5	23.1	22.3	
10	Rod №2	24.5	24.4	23.5	-1.1
	Rod №1	23.4	24.2	22.2	

Tabl.2 Meteorological book

ANALYSIS

Adjustment of a test leveling line with 22 leveling distances was performed. The test section is approximately 30 km long and it is between two Fundamental leveling benchmarks. The cross section of leveling is given in fig. 2.

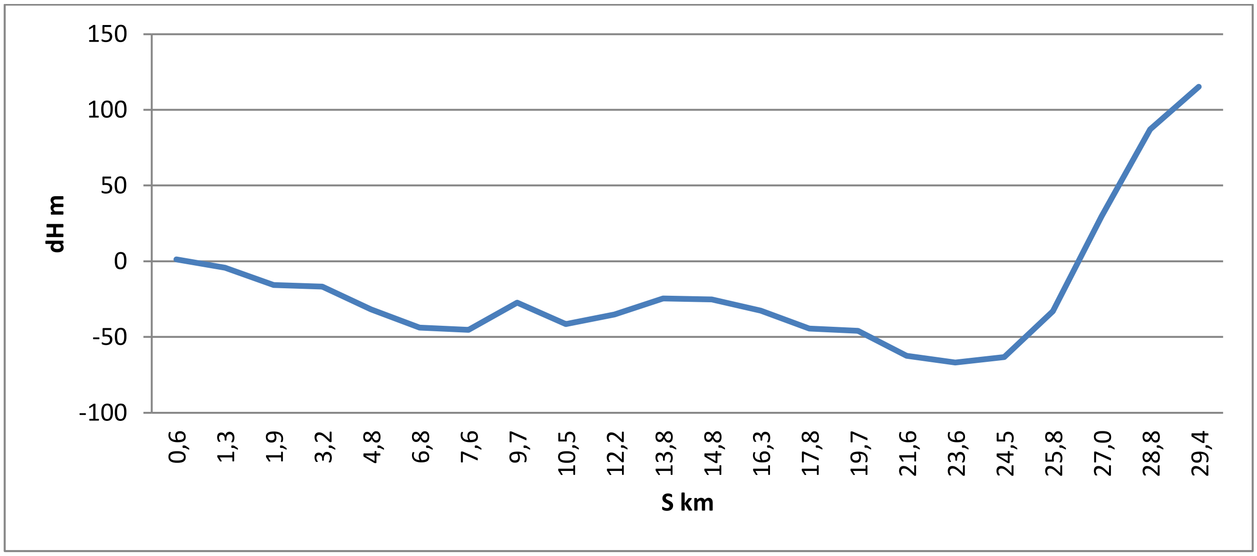

Fig.2. Cross section of leveling

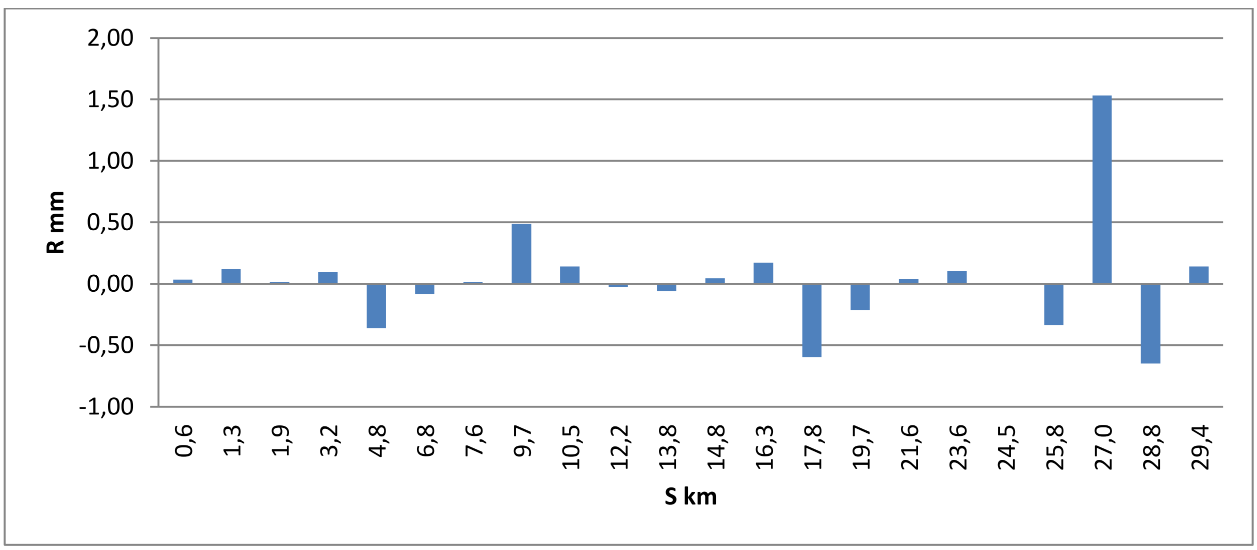

Fig.3. Refraction correction values

The obtained values for refraction correction for the whole length of the test line is 0.6 mm and for the every leveling distance is given in Fig. 3. For every leveling distance it varies from 0 mm. to 1.5 mm. The largest values of refraction correction are observed in the leveling distances with highest terrain slope. Leveling successive distances with positive and negative difference of elevation, the refractive error is not compensated. For example, for the length of km. 6.8 to km. 19.7, the Refraction correction value is 0.6mm, although the difference of elevation between the endpoints is almost zero, and line going through sequential climb and descent.

The measured temperatures give a significant impact on the value of the systematic refractive error (correction respectively). Numerous meteorological publications show that in the night the ground is colder than the air just above it. Soon after the sunrise temperature of the air is decreasing with the height and the temperature of the ground becomes higher than the temperature of the air just above it. For this reason the temperature gradient is negative at day and positive at night. The absolute values of the vertical gradient are greater in the clear sky, day or night (Kukkamaki, 1978).

Measurements of the temperature should be done with aspiration thermometers (with forced air flow) to obtain maximum reliable temperature gradient values. Thermometer readings should be monitored and evaluated. In order to be acceptable, the temperature differences between the upper and lower thermometer of the rods should be between -3.0°C and 1.0°C. Also the difference between the temperature differences of two successive setups should be between –3.0°C и 3.0°C (NOAA, 1999). If the measured temperatures are outside these limits, it is advisable not to conduct leveling measurements until the cause is eliminated or the weather conditions are improved.

In processing and analyzing measurements in the test section, the temperatures that do not meet the above conditions are excluded from processing. Instead, only the thermometers of one rod are used or temperatures are interpolated from previous and next set-up.

CONCLUSIONS

The results obtained show that the refraction correction is commensurable with the correction for the difference between the average of the rod meter and the reference. This correction must be applied for each set-up and it not eliminated with the same positive and negative differences of elevation. The largest values of refraction correction are observed in the leveling distances with highest terrain slope. Measurements of the temperature should be done with aspiration thermometers simultaneously with measurements of the leveling. Incorrectly measured temperatures have a negative impact and they can lead to wrong calculated correction and contaminated final results. It is recommended to perform experimental research and to develop a model for the vertical refraction that is suitable for the territory of Bulgaria. The applying of refraction correction does not eliminates the requirements associated with balancing of the length of sights, maximum length of sight, minimum high of sight, and the choice of appropriate weather conditions.

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