AFFECT OF MEASUREMENTS CONDITIONS ON THE SIZE OF REFRACTION ANGLE

Wojciech Sowa[1]

Abstract

Paper presents calculations which shows dependences between conditions of vertical angles measurements and the size of vertical refraction angles. It presents attempt to calculate refraction corrections also.

Keywords

Vertical refraction angle, correction of refraction, monitoring system

1 REFRACTION PHENOMENON IN MEASUREMENTS

In deformation measurements, carried out to ensure the safety of engineering objects, tachimetric method is used very often. It allows to determinate displacements of controlled points with high accuracy. The use of this method is result of development of monitoring systems, which uses automatic total stations. These instruments allows to make permanent measurements without human interruption. Coordinates are calculated automatically also, what allows to permanent monitoring of object and detect dangerous changes.

To determine the height of the controlled points they uses trigonometric leveling. Difference of height is calculated on the basis of measured spatial distance between tachimetric stand and controlled points and vertical angle. On the value of the latter, especially at large distances, affects phenomenon of vertical refraction.

1.1 Description of phenomenon

Phenomenon of refraction is light rays sagging. Visible effects of refraction are: distortions of Sun and Moon discs, mirages, changing times of sunrises and sunsets of celestial object, changes of vertical distances of observed objects.

There are many types of refraction, including vertical atmospheric refraction caused by heterogeneous nature of Earth's atmosphere. The refractive index of atmosphere is variable and usually increases with decreasing altitude. It is directly dependent on the pressure and temperature as well as a certain degree of humidity. For easier understanding of the phenomenon, the Earth's atmosphere can be thought as an area composed of thin layers of homogeneous optical properties. According to Snell's law, the light passing through layers, on their boundary changes direction of its course, and sag. Assuming that the layers are very thin, the track of the beam can be considered as arc or curve. As a result, the observer cannot see the real position of the point, but his apparent image distorted by the phenomenon of the light refraction.

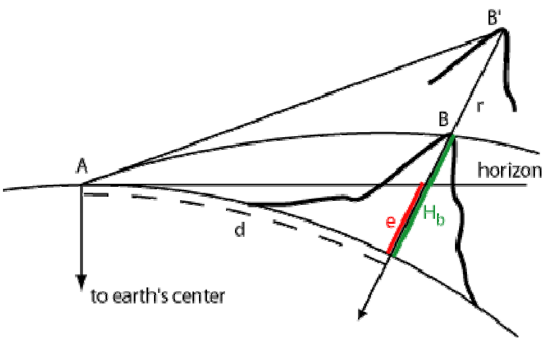

Fig. 1 *Phenomenon of atmospheric refraction*

In surveying, the phenomenon of refraction the most significant impact has on the results of measurements of the vertical angles in trigonometric leveling. The observer carrying out the measurement, sees an apparent image of the point. Measured zenith angle is then the angle between the zenith and the tangent to the curve (light path), while the true zenith angle is shifted by the so-called angle of refraction. The most common case is the situation, in which the true zenith angle is greater than the measured. This is due to the curve of refraction, which is usually directed bulge of the Earth. In practice to eliminate of the refraction impact the refractive index (k) is used. It was calculated as the ratio of the Earth radius to the radius of curvature of the track, on which light moves, and given in the tables for the specific conditions of making measurements. On territory of Poland shall be equal to the value of 0.13 and it is assumed in all measurements performed in the country. Studies conducted by various authors, as well as calculations performed in the

[1] Wojciech Sowa, M. Sc., Eng. Wrocław University of Environmental and Life Sciences, Intsitute of Geodesy and Geoinformatics, Wrocław Grunwaldzka 53, Wojciech.Sowa@up.wroc.pl

paper, shows the fallacy of such proceedings. As will be shown later, the true angle of refraction takes different values (smaller or larger than zero) depending on the conditions under which the measurement was made.

1.2 Conditions which have impact on refraction phenomenon

Based on the literature and previous research, seven condition of making measurement, which have impact on the size of refraction angle were chosen. Those are: temperature, temperature gradient, humidity, air pressure, wind speed, distance between measuring station and controlled point and average height of sight line above the ground. The impact of individual factors on the value of the refractive index has been repeatedly tested and described in the literature. Most frequently mentioned factors are air temperature and atmospheric pressure. This relationship is clearly present in the results of astronomical observations, performed by Auer and Standish [1], who performed the measurements for different vertical angles and with varying values of temperature and air pressure .The results of their work show the significant impact of these factors on the value of the angle of refraction. In the table T_W is the air temperature in Kelvin degrees, P_W is the atmospheric pressure in mercury millimeters. The left column shows the values of vertical angles in degrees for which the atmospheric refraction angles were calculated.

Zenith Angle (deg)	$T_w = 273.15$, $P_w = 760$,	$T_w = 273.15$, $P_w = 780$,	$T_w = 303.15$, $P_w = 760$,
15......	16".14	16".56	14".54
30......	34.77	35.68	31.32
45......	60.17	61.76	54.20
60......	103.99	106.73	93.65
75......	221.49	227.33	199.15

Fig. 2 *Dependence between zenith angle and temperature and air pressure [1]*

According to the researchers, which Kharaghani refers in his work [2], a factor that has less impact on the value of the angle of refraction is the humidity. Water vapour is closely related to the air temperature and other weather conditions.

Phenomenon, which significantly affects on the size of the refraction angle is a vertical temperature gradient (change of the temperature with a height change). Gradient is also closely related to air temperature, time of day or year. Very strong influence on the phenomena has the soil capacity to absorb and return heat energy. At the time when sunshine is large and the temperature rises, some of the energy is absorbed by the substrate, which causes changes in the mass of air in the atmosphere above it. Temperature decreases with height, which results in a negative value of the temperature gradient. The result is sagging of light rays to the top - the refractive index is less than zero.

The reverse situation is when the sunlight decreases and the Earth's surface reflects the accumulated energy. Then the lower layers of the atmosphere have lower temperature than the higher, so the gradient is positive. The effect is similar - light rays refract to the bottom, the curve takes convex shape, and the refractive index is positive.

Another atmospheric factor which affect on the refraction may be wind speed. Depending on the wind strength, the air mass, for example, from above the water tanks, characterized by a humidity greater than those above the dry land, can move and mix. A similar situation may apply to the so-called updraughts - air masses over highly heated area (usually sandy or rocky) forming a funnel shape. Wind can move the mass, causing a local temperature change, and thus to affect the refractive index of the particular air layers.

In the publication [3], the average height of the sight line over the surface is correlated with the phenomenon of refraction. The results presented it the paper show that the height of the target, changes the way it affects on the refraction. When the target is relatively low over the ground, that is, to a height of several meters, a beam of light curves in the direction of the zenith, which means that the refractive index of k is less than zero. Sight lines with an average height of more than a dozen meters, give opposite results, the refractive index has a value greater than zero. Determination of the exact value of average height above the surface of the target is a big problem and needs to prepare large amounts of additional measurements which would enable the execution of field profiles.

Length of the sight line, as can be seen from several works [4, 5, 6] also affects the size of the vertical refraction angle. The reasons for this association may be due to the correlation that exists between the length of the sight line and its average height above the ground. The results presented in the works seem to be consistent with the claim that the refractive index is positive for targets located relatively far away from tachimetric stand and negative for these located near.

There are many factors that have a direct or indirect impact on size of refraction angle. A large number of results, seems to confirm the relationship between the phenomenon of vertical refraction and individual factors, what allowed to carry out further research to find a direct relationship and dependencies between them.

2 DATA

Used data is observations of structural monitoring system from the period of the year, supplemented by data from periodic measurements of precise leveling. They are basis for the calculation and analysis presented in the paper.

2.1 Object of research

Data are derived from an object located in the province of Lower Silesia near the Żelazny Most village. Tailings reservoir is the largest facility of its kind in Europe. Construction of the reservoir began in 1974, and it works from February 12, 1977. Basic data on the reservoir are:

- Total area - 1394 hectares
- Total cubature - 340 million cubic meters,
- dams length - 14.3 kilometer,
- dam height - from 20 to over 60 meters,
- the volume of water in the reservoir - 8 million cubic meters,
- Maximum depth of water - about 2.5 meters.

On the location of the reservoir affects the natural terrain and the location. Wastes are transmitted with pipelines from over 30 years in the form of a mixture of silica and water. Due to the method of storage, the size and shape of the reservoir are constantly changing [7].

2.2 Measurements

To ensure the security of the reservoir, half a year after the start of exploitation, deformation measurements started. Research conducted for nearly four decades by teams from the University of Science - Technology in Krakow, which twice a year, measures the research network (380 points) around the object. Since 2008, the monitoring of part of the eastern dam is carried out using a Leica GeoMoS system. The dam at this point has a height up to 60 meters [7].

The system works continuously since December 30, 2008. In this case, it uses tachimeter Leica TCA2003, GNSS receivers: Leica GRX1200 on the reference station and two GMX902GG (reference point and control of tachimetric stand position), two Nivel210 inclinometers and meteorological sensors. All data is collected and analyzed by Leica GeoMoS software [7].

23 points controlled by the system, are located at distances oscillating in the range of 130 - 490 meters, while the largest height difference between them is about 45 meters. Picture showing measuring network is shown below (fig.3):

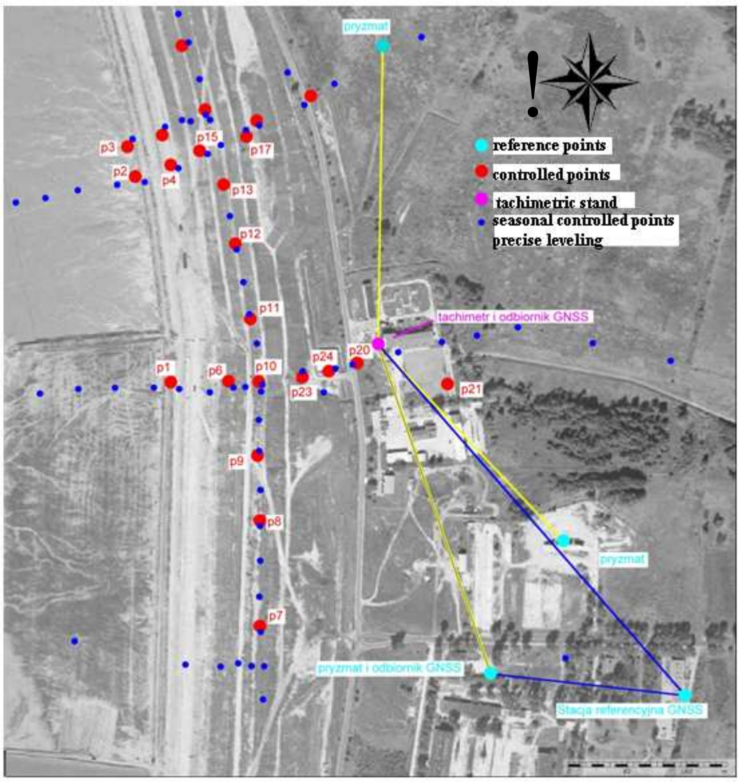

Fig. 3 *Measuring network – Żelazny Most*

Measurements are performed every hour, total station measures the location of the controlled points in two faces, recording the horizontal and zenith angle, as well as the spatial and horizontal distance. The system also records the temperature and pressure during the measurement.
To calculate the angle of refraction is necessary to know the "real" (more likely) height differences between the tachimetric stand and controlled points. Seasonal measurements were carried out using precise leveling techniques using Leica DNA03. In addition, data from a meteorological station located below the tachimetric stand were used.

3 DEPENDANCES BETWEEN CHOSEN MEASUREMENTS CONDITIONS AND REFRACTION ANGLE

Presented in the paper research are intended to define the relationship between the size of the refraction angle and factors describing the terms and conditions of planned measurement. Correlation between refraction angle and chosen factors were calculated using data obtained from Leica GeoMoS and the course of the variation was presented in the charts. Calculations of refraction corrections using linear regression method were made.

3.1 Preparing and choosing data

Linear regression equation, used to calculate the corrections of refraction, were determined in the thesis of Filipiak and Kożuch [8, 9]. They identified factors of the equations, which allowed to designate corrections in selected periods:

Calculation performer	Period of measurements	Pr*ec*ise leveling time	Regression equation for a period
Filipiak J.	Spring	01.04.2009 – 03.04.2009	27.06.2009 – 05.04.2009
	Summer	22.06.2009 – 01.07.2009	21.06.2009 – 30.06.2009
Kożuch K.	Autumn	07.11.2009 – 08.11.2009	03.11.2009 – 13.11.2009
	Winter	25.02.2010 – 27.02.2010	21.02.2010 – 03.03.2010

Tab. 1 *Periods of corrections designation*

In this study, regression equations derived in thesis of Kożuch and Filipiak, were used to determine corrections for observations made one year after period of their designation. For this purpose, 21 days of measurement shifted by one year from this period were selected:

Period	No.	Datum
autumn	1	24.09.2010
	2	08.10.2010
	3	22.10.2010
	4	05.11.2010
	5	19.11.2010
	6	03.12.2010

Period	No.	Datum
spring	13	02.03.2011
	14	01.04.2011
	15	08.04.2011
	16	22.04.2011
	17	06.05.2011

Period	No.	Datum
winter	7	17.12.2010
	8	30.12.2010
	9	14.01.2011
	10	28.01.2011
	11	11.02.2011
	12	25.02.2011

Period	No.	Datum
summer	18	20.05.2011
	19	03.06.2011
	20	17.06.2011
	21	30.06.2011

Tab. 2 *Days selected to calculate refraction corrections*

For chosen days, the division on the time of day, according to the contractually agreed hours:

Day period / Year period	Morning (R)	Day (D)	Evening (W)	Night (N)
Autumn (j)	7:00-11:00	11:00-14:00	14:00-17:00	17:00-7:00
Winter (z)	7:00-11:00	11:00-15:00	15:00-18:00	18:00-7:00
Spring (w)	7:00-12:00	12:00-16:00	16:00-20:00	20:00-7:00
Summer (l)	5:00-10:00	10:00-16:00	16:00-21:00	21:00-5:00

***Tab. 3** Day division for every year period*

For calculations four points with numbers: 2, 3, 16 and 18 were chosen. Points were located in distances from 250 to 490 meters from tachimetric stand.

3.2 Calculation of refraction angle

To calculate 'real' or so called 'true' vertical angle, formula 1 was used:

(1)

In which:

vertical angle

height difference between tachimetric stand and controlled points

spatial distance between tachimetric stand and controlled point – data from structural monitoring system

Seasonally precise leveling measurements made possible to determine ‚real' (more probably) heights of controlled points and the instrument.

Vertical angles were obtained from the data of the structural monitoring system. They were measured at hourly intervals for each point, provided that the measurement was possible. For all available data, the ‚real' vertical angles were calculated according to the formula 1.

Comparing the ‚real' angle to the angle measured by the instrument (net of the central angle of the Earth), vertical refraction angle was calculated:

(2)

in which:

refraction angle

'real' vertical angle (derived by formula 1)

measured vertical angle

central angle of the Earth (derived by formula 3)

(3)

in which:

D_{ik}^{hz} – horizontal distance between tachimetric stand and controlled points in kilometers.

For chosen points and observation days, the angles took negative values, which means that the convex of refraction curve was directed towards the ground.

3.3 Study of dependences between refraction angle and measurements conditions

In this study seven factors (the measurement conditions) that affect the size of the vertical refraction were adopted. The following table presents the designation and units of factors:

No.	Factor	Unit	Designation
1	Pressure	mBar	pres
2	Temperature	°C	temp
4	Temperature gradient	$\frac{°C}{m}$	Dt
5	Average height of sight line	M	Hc
6	Wind speed	$\frac{m}{s}$	Wind
7	Humidity	%	Wilg

***Tab. 4** Units and designations of chosen factors*

To analyze the relationship between factors (selected 5) and the vertical angle of refraction, the correlation coefficient was calculated, between the weather conditions and the angle value, assuming the linear relationship. Calculations were performed using the following formula:

(4)

in which:

correlation coefficient

covariance between X and Y values

standard deviation

The correlation coefficient can assume values from - 1 to + 1. The higher the absolute value, the data is more correlated, the sign represents the nature of this correlation. Negative values - inverse proportional, positive - directly proportional. Coefficients equal or close to zero means no correlation between the variables. The highest correlation with the refraction angle for all observations shows air temperature, for which the average value of the correlation is -0.391. However, depending on the season, day of measurements and height of sight line, correlation assume various values.

Due to the high variability of the correlation coefficients, it was decided to make daily charts showing changes of the refraction angle and conditions of measurements. Example of that chart is presented in figure 3:

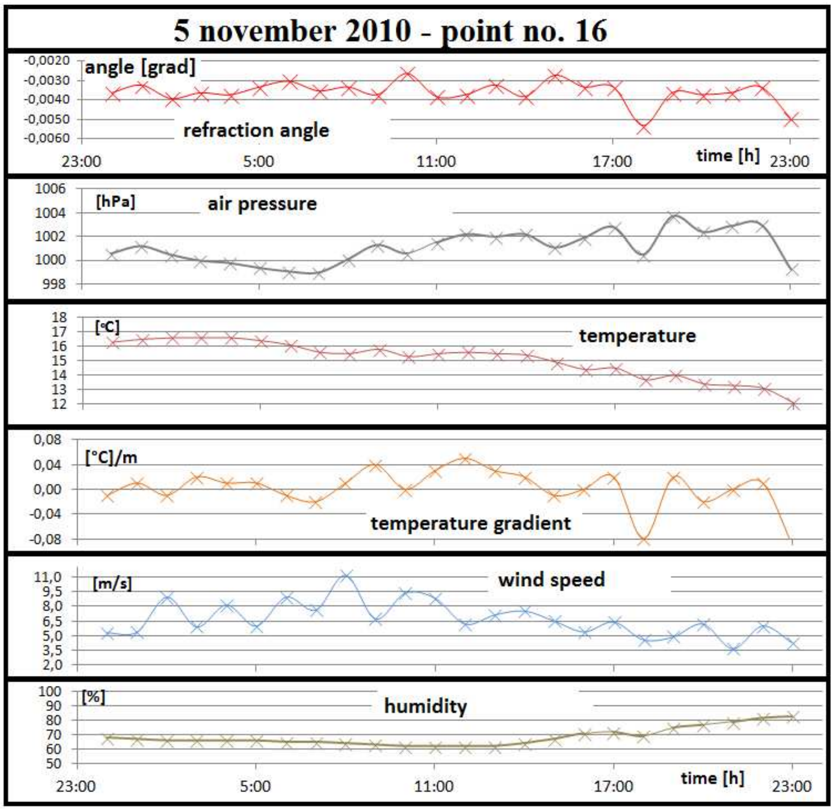

***Fig. 3** Daily chart of refraction angle and chosen measurement conditions*

Charts and correlation coefficients showed that vertical refraction angle depend on different factors in variable way. Dependences are variable in time, for different year and day periods. It allows to make an attempt of designation corrections with use of these factors.

4 REFRACTION CORRECTIONS

Refraction corrections, used to correct measured vertical angles, were calculated by using linear regression method:

(5)

in which:

refraction correction

linear regression coefficients

variables of the equation – chosen measurement conditions

In the calculations of refractive corrections all of the variables (seven) were adapted: pressure, temperature, horizontal distance, temperature gradient, the average height of sight line, wind speed and humidity.

4.1 Calculations

Calculations were made according to the formula 6:

(6)

Corrections have been added to the measured vertical angles, then compared with calculated ‚real‘ angles. That gives corrected refraction angles:

(7)

in which:

corrected refraction angle.

4.2 Results

Calculated corrected refraction angles were compared to ‚real‘ refraction angles. Example of that comparison for four points on 5 November 2010 is presented on the charts below:

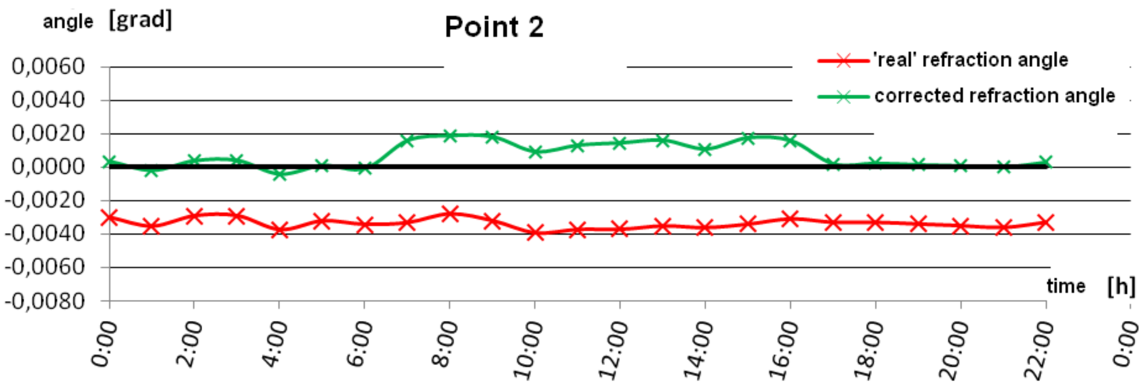

Fig. 4 *Daily chart of corrected and 'real' refraction angle – 5 November 2010 – point 2*

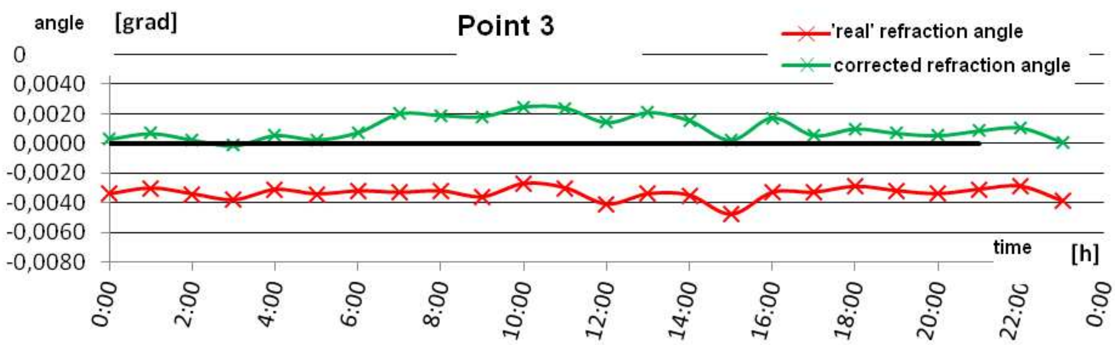

Fig. 5 *Daily chart of corrected and 'real' refraction angle – 5 November 2010 – point 3*

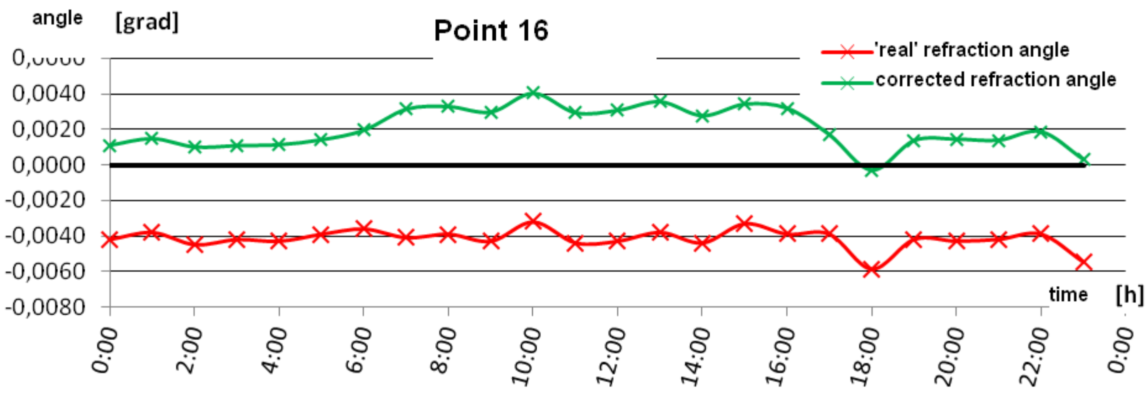

***Fig. 6** Daily chart of corrected and 'real' refraction angle – 5 November 2010 – point 16*

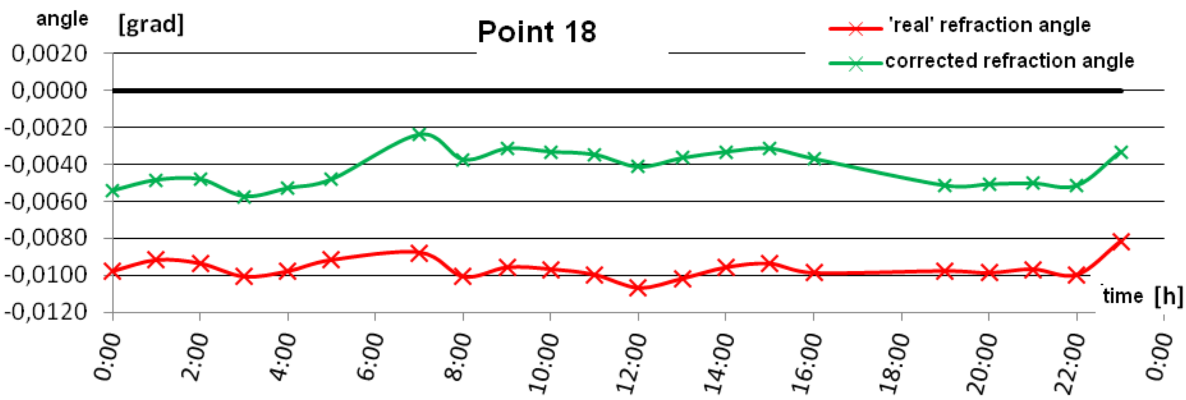

***Fig. 7** Daily chart of corrected and 'real' refraction angle – 5 November 2010 – point 18*

Analyses of all graphs allowed to formulate a statement, that for the days corresponding to days in which the regression equations were determined, the corrections meet the task, and reduce the absolute value of the refraction. For days in which linear regression equations was not designated, the effectiveness of the corrections is lower.

To determine the usefulness of the method, the analysis of the results was performed. The absolute values of the angles of refraction was compared to corrected values of the refraction angles. If the second value was less than the first, correction was considered as effective – improving measurements results. As a result of this comparison, the following amounts of the corrected observations was given(for 1212 observations):

- for variant I – division of data taking into account the time of year, time of day and the average height of sight line above the ground - 879 improved values
- for variant II – division of data taking into account the time of year - 623 improved values
- for variant III – division of data taking into account the time of year - 606 improved values
- for variant IV – division of data into periods: autumn - winter and spring - summer - 689 improved values

5 SUMMARY

Carried out calculations shows that the phenomenon of refraction affects on the vertical angle measurements and it is reasonable to study this phenomenon. Values of refraction angles calculated for chosen days are in the range: -0,0115 to 0,0046 grad. That values in measurements of vertical angles (measured with accuracy reaching 0,0003 grad) might have significant impact on the results.

Analysis of correlation between the refraction angle and chosen conditions of measurements leads to the conclusion that it depends on the selected conditions in a different way. Nature of this relationship is related to the period of the year and time of the day.

Calculated refraction corrections gave results that allow to establish the suitability of this method. Better results are obtained for periods which coincide with the periods for which coefficients of equations were assigned. Results allow to carry on research on the chosen method and its application in engineering measurements.

LITERATURE

[1] AUER Lawrence H, SANDISH Myles E., *Astronomical Refraction: Computation for All Zenith Angles.* The Astronomical Journal 119(5) , 2000, 2472.

[2] KHARAGHANI G. A., *Propagation of refraction errors in trigonometric height traversing and geodetic levelling*, University of New Brunswick: Surveying Engineering, 1987.

[3] CACOŃ S., KONTNY B., MĄKOLSKI K., STOPYRA R., *The local space network as the multifunctional basic geodetic system*, Wrocław: Zesz. Nauk. AR. Wrocław, Geodezja i Urządzenia Rolne IV, z.167, 1987. 59 – 69.

[4] IZOTOV A.A., PELLINEN L.P.,*Research of a terrestrial refraction and methods of geodetic leveling*, Moscow: Works CNIIGAiK, vol.102, Publishing „Geodesy“, 1955, 175.

[5] *MĄKOLSKI K., Wpływ środowiska kopalni odkrywkowej na dokładność określenia odległości zenitalnej i współrzędnej wysokościowej w sieci przestrzennej,* Akademia Rolnicza we Wrocławiu: Doctoral thesis, maszynopis Akademia Rolnicza we Wrocławiu, 1987.

[6] WEI DONG-SHENG, *Precise analysis for EDM trigonometric leveling*, China: Water Sciences and Engineering Technology, CNKI – electronic platform – 2008 [cit. 2012-07-02].

[7] *Żelazny Most pod obserwacją*, Geodeta 04/2012, 2012, 8 – 13.

[8] KOŻUCH K., *Influence of some environmental conditions on the value of refractive corrections in the measurement zenith angles*, Wroclaw: Wroclaw University of Environmental and Life Sciences, MSc Thesis, 2010.

[9] FILIPIAK J., *Analysis of the impact of environmental conditions on the accuracy of height coordinate determining in maintenance-free monitoring measurements,* Wrocław: University of Environmental and Life Sciences, MSc Thesis, 2009.

REVIEWER

Krzysztof Mąkolski, Dr Eng., Wrocław University of Environmental and Life Sciences, Institute of Geodesy and Geoinformatics, assistant professor, Wrocław Grunwaldzka 53, krzysztof.makolski@up.wroc.pl