Development of methodology for reducing errors of GPS measurements and its approbation in the open pits of Kazakhstan

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Abstract. The article discussed in detail the issue for the Study of errors GPS associated with "multipath" satellite signals at work on the open pit mining. There was carried out the analysis of GPS errors of the ionosphere and troposphere condition at the north latitudes. Studied in detail the error "shadow effect", which is important in GPS measurements on the lower levels of open pits. There was developed a special device reducing the receiving of the distorted satellite signals which increases the accuracy of measuring. In the work there is studied the error of GPS antennas orienting in measurements. Derived a formula for the permissible remote distance of measurements from a slope using GPS in mode of kinematics. The results of the study have been approbated at Kazakhstan open pits.
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Introduction

Currently, for problems solving to determine displacement of open pit slope and the velocity of displacement the Earth's surface is increasingly used by high-precision GPS measurements. Practice of GPS in the open pit accompanied by a process of accumulation errors. Among the errors can be identified systematic errors related correction clock receiver regarding satellites and the error associated with the location of the satellites and their trajectory, as well as a natural component. The natural errors traditionally include errors in the ionosphere and troposphere, as well as "multipath" satellite signal. These errors affect the accuracy in measurement GPS, and therefore very important by perforce its reduction for measurement. In the article gives a detailed error analysis of GPS and methods to reduce them. Research on "multipath" satellite signal, so-called "shadow effect". GPS measurements in open pits is always accompanied with the error, since the work is carried out on the lower levels of the open pit where it is difficult advancing of undistorted satellite signal and in the immediate vicinity of slopes, where there is a "shadow effect". To reduce the reception of signal with accumulated errors developed a special antenna allows to improve the accuracy of measurement. The results of measurements are introduced in the open pits "Varvarinskiy", "Sokolovskiy" and "Vasilkovskiy" Republic of Kazakhstan.

1. GPS's errors

Studying with Global Positioning Systems (GPS) and validation with the ground truth data help reveal a number of errors that can influence determination of coordinates (Figure 1). The errors can divided into the following types [1, 2]: ionosphere refraction (45%), satellite geometry (38%), ephemeris data (6%), signal bouncing (4%), tropospheric refraction (3%), satellite timer (3%) and receiver (1%).

The Ionosphere error

The table shows the ionospheric delay for some frequencies and for two values of the TEC (Total Electron Content). Evident that on frequency range L1 and L2 ionosphere exert a big impact. Usually the quantity of the TEC is within at 1016 to 1018 [3,4].

Table 1. Ionospheric correction in the range

Frequencies	TEC=10^{16} (el/m^2)	TEC=10^{18} (el/m^2)
F_{L1}	0.260	26.0
F_{L2}	0.160	16.0

The ionosphere error observed in the received signal delay and the beam trajectory curving and can be obtained by the program, Communication Alert and Prediction System (CAPS), a system of warning and predicting the state of communication, developed by NASA [5]. The ionosphere refraction introduces an error in the measurement of the order 4-5 m.

In the program CAPS choose the place, date and time of measurement. Due to color scale, obtain the electron concentration on the measured area.

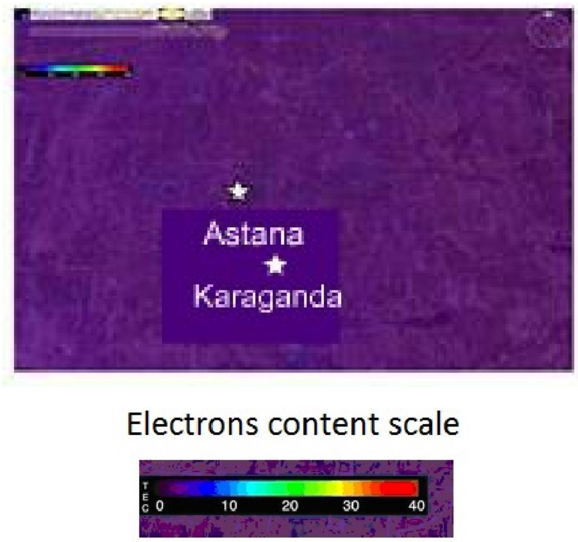

Figure 1. Determining full electronic concentration

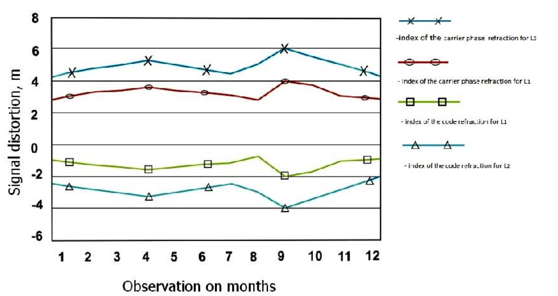

Figure 2. Diagram of the electromagnetic signal refraction by the carrier phase and by the code within a year for Central Kazakhstan

The electromagnetic signal delay leads to the error of defining coordinates by the code and the phase of the carrier. The electromagnetic signal refraction index for the carrier phase and the code in the ionosphere can be written down as follows [6, 7, 8, 9]:

$$n_\varphi = 1 - \frac{\alpha N_e}{f^2}, \; n_P = 1 + \frac{\alpha N_e}{f^2} \qquad (1)$$

Where α is a constant equal to 40,28 $Hz^2 \times m$;

N_e is electron concentration, $1/m^2$;

f is electromagnetic signal frequency, Hz.

The carried out calculation of the electromagnetic signal refraction factors for the carrier phase and by the code at two frequencies for Central Kazakhstan in 2012 is shown in Figure 2.

Troposphere effects

The troposphere refraction error introduces an error in the measurement of coordinates of the order 2.00m - 2.500 m in the direction of zenith. Troposphere is a non-dispersing medium, that is error can not be excluded by means of combining measurements at the frequencies L_1, L_2 or by the effects similar to the measuring of pseud-orange - both by the carrier code and the phase. When determining the error of GPS it is necessary to use a refraction index N [10, 11, 12, 13, 14]:

$$N = A\frac{P}{T} + B\frac{e}{T} + C\frac{e}{T^2}, \qquad (2)$$

Where P is pressure, Pa;

e is water vapor partial pressure, Pa;

T is temperature, K;

A is a pressure coefficient, equal to 77,6 K/Pa;

B is a water vapor coefficient, equal to 72,0 K/Pa;

C is a coefficient equal to $3{,}75 \times 10^5$ K^2/Pa.

On the official website of "Kazgidromet" take average statistical temperature for each month throughout the year [15]. By the data obtained let's build a diagram of the refraction factor deflection on months for the territory of Central Kazakhstan.

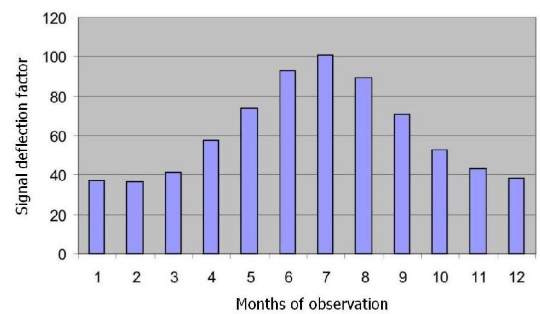

Figure 3. Diagram of the refraction factor deflection on months

Using the above plot it is possible, from a day of observations, to know how to eliminate the refraction error for the signal passing through troposphere at that period of time of the day.

***2.* Research to reduce «multipath propagation» and phase center**

In the process of the "multipath propagation" an electromagnetic signal from the satellite achieves the receiver antenna through several ways of returning: from the neighboring objects, underlying surface, transport vehicles and other objects alongside with the immediate true electromagnetic signal [3].

In order to cutoff the waves returned from the earth, there is used a metallic disc (Figure 4).

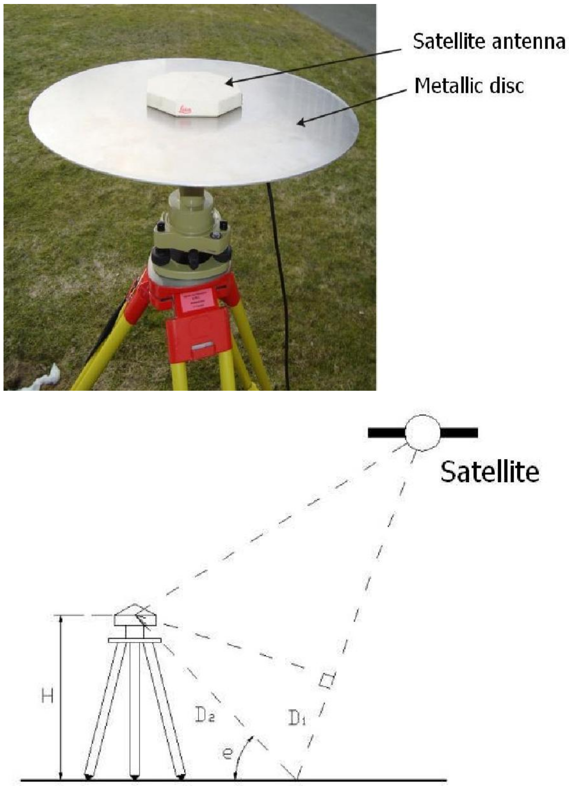

Figure 4. Antenna with a disc for cutting off return signals and determining GPS accuracy with different position of the receiver antenna height

A satellite signal returned from the surface passes an additional path and increases the error of measurement. Where *H*- is instrument height, m, *e* - is angle of elevation the satellite above the horizon, deg and D_1, D_2 -is extra distance traveled by satellite signal, m.

There was carried out studying the dependence of a measurement error on the measuring height with changing the tripod height 1,5 m, 1,75 m, 2,0 m with a metallic disc. At each station in the "kinematics" mode there was carried out up to 50 measurements and was determined the arithmetical average. Within the measuring period there were no GDOP high jumps and there were no satellite signals.

Table 2. Results of measurements in the "kinematics" mode for studying the "multipath propagation" effect on the measurements accuracy with different heights

Height, m	Without metallic disc			GDOP	With metallic disc			GDOP
	X, m	Y, m	Z, m		X, m	Y, m	Z, m	
1,5	0,0034	0,0023	0,0068	3,3	0,0022	0,0013	0,0046	3,3
1,75	0,0044	0,0025	0,0119	3,4	0,0042	0,0021	0,0068	3,3
2	0,0055	0,0028	0,0149	3,3	0,0053	0,0024	0,0097	3,3

Studying the effect of a metallic disc effect on the measurement accuracy was carried out in the mode "fast statics" and made 20 minutes at each station. The measurement error in this mode reduced by 10 %, and by the height the error reduced by 15% (Figure 5).

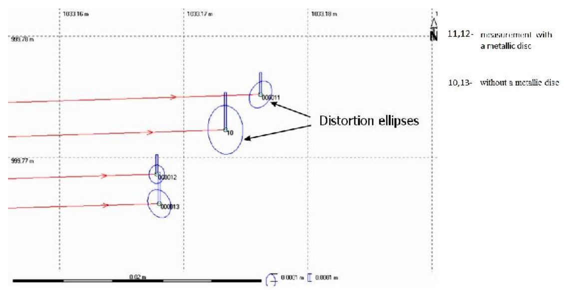

Figure 5. Obtaining ellipses of curving in the program SKI-Pro

2.1 Studying the effect of the antenna phase center on the measurement accuracy

In ideal circumstances, the phase center of GPS receiver antenna is defined as the center of wave front in radiation field. But in practice, the wave front will fluctuate caused by the characteristic of antenna and machining art, etc, and the locations of every signal reception do not overlap. Therefore, GPS receiver antenna phase center is the instantaneous location where the GPS signal is actually received [16, 17].

Studying GPS antenna of Leica AT 501 receiver showed that when measuring at different angles of the antenna 0^0, 90^0, 180^0, 270^0, 360^0 in the mode "fast statics" the results differed by the location due to the phase center position instability (Figure 6). That's why when observing at the open pit it is necessary to orient in the same direction, that is to the north.

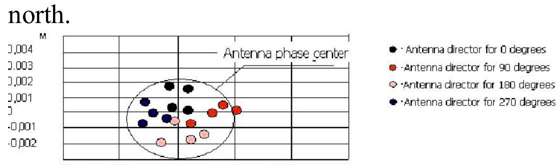

Figure 6. Phase center stability of Leica AT 501antennas

2.2 Studying the "shaded effect" on the GPS measurement accuracy

To increase the accuracy of observing, measurements were carried out using specially developed robust tripods where there is mounted a horizonted and centered tribrach with antenna. With the bench height 12 m there were put points at the distance L_1=15m; L_2=10m; L_3=5m from the slope (Figure 7).

The main task of this study is defining of the allowable distance at which there must be located a working benchmark from the slope in order to eliminate the shaded effect error when observing the open pit slope displacements.

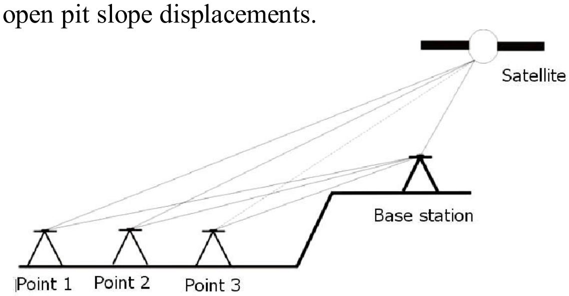

Figure 7. Scheme of defining a shaded effect

The obtained data of excess errors in trigonometric leveling and the errors of GPS measuring are presented in Table 3.

Table 3. Results of mean-square errors of measurements

Mean-square error of measurement	Allowable error in trigonometric leveling, mm	Measurement error in GPS, mm
Planned	6,4	3,8
Height	6,8	6,3

By the data obtained there can be made a conclusion that the measurement error when moving to the slope increases, and there can be derived a formula for measuring in the kinematics mode [10]:

$$m_{\text{доп}} = 0,292H, \quad (3)$$

Where H is the slope height, m.

3. Using of GPS in the Mines of Kazakhstan

At present GPS is widely used in some open pits of Kazakhstan. For example, at the ore pits of the Vasilkovskiy mining-concentration complex, of the Varvarinskiy deposit, the surveying services teams work with the Two-frequency 1200 Leica GPS, and at another at the coal pit "Shubarkol" with One-frequency 500 Leica GPS.

Using of GPS at the Varvarinskiy deposit

Depending upon the visibility and other appropriate conditions, at the south-east edge of the open pit, three observation stations were put in August, 2009 .The figures 8 show the position of the stations in the mine and that of the base station, respectively.

The observations were carried out for the three months of 2009: August, September and December.The system of monitoring the edges and the walls of the mine for their movement allowed us to monitor and evaluate its stability (Table 4).

Table 4. Results of observations at open pit "Central" of the Varvarinskiy deposit on points RP1, RP2 and 1 of range 1

	1st cycle August 26, 2009					2-d cycle September 24, 2009				
	range 1					range 1				
	X,m	Y,m	Z,m	d,m	Δh,m	X,m	Y,m	Z,m	d,m	Δh,m
RP1	3362.345	28430.446	205.043			3362.307	28430.451	205.069		
RP2	3340.928	28450.243	204.99	29.165	-0,053	3340.926	28450.241	205.001	29.133	-0.068
1	3309.382	28479.406	204.59	42.961	-0,400	3309.380	28479.408	204.587	42.963	-0.414
			3d cycle December 4, 2009							
			range 1							
	Difference between I and II series		X,m	Y,m	Z,m	d,m	Δh,m	Difference between II and III series		
	d I-II,m	Δh I-II,m	3362.204	28430.523	205.107			d II-III,m	Δh II-III,m	
			3340.858	28450.26	205.017	29.072	-0.090			
	0.032	0.015	3309.343	28479.434	204.606	42.946	-0.411	0.061	0.022	
	-0.002	0.014						0.018	-0.003	

It is clear from the table 4 that the mine walls were experiencing both compressive and tensile strain on account of the new faces being exposed nearby, blasting and other related parameters; thus resulting in balancing of stress as it was being developed.

At the Sokolovskiy open pit

For observing the open pit wall deformations in the mine there were four observation stations I, II,III and IV where the benchmarks were put on the upper ground and the berms of the open pit bench edges perpendicular to the spreading of the upper edge border (Figure 8).

The observation station is put in the zone of the crack at the west edge of the open pit to the horizon – 125 m, the project stipulated forming a ground station consisting of five profiles.

The analysis of the results of measuring using an electronic total station Leica TCA 1202 showed the following disadvantages of using this methodology:

- visibility limitation between the working benchmarks in connection with a large open pit depth, benches height, existence of industrial structures on the open pit edge lead to the necessity of forming the additional transition points which increases the amount of works and accumulating the error of transiting height and plan coordinates.

Determining the point coordinates of observation station I at deep horizons were carried out by the way of inserting an additional transition point using GPS technologies. The insertion of an additional transition point at the west edge IE-6 at horizon -25 m was made using a total station Leica TCA 1202 and two-frequency receiver GPS Leica 1200. GPS measurements were carried out in the mode of fast statics with accuracy up to $(1 – 3) \cdot 10^{-3}$ mm. The results of measuring are presented in Table 5.

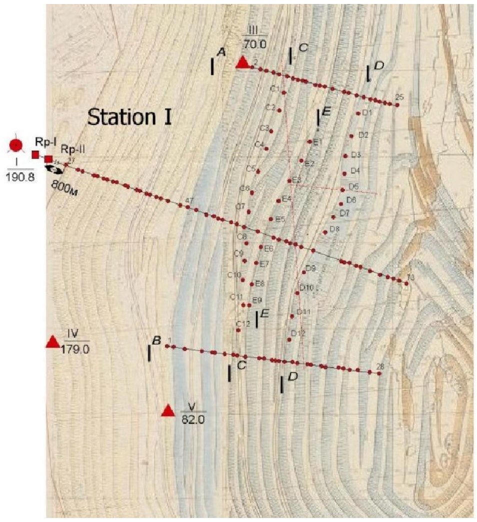

Figure 8. Observation station I at the Sokolovskiy open pit

Table 5. Results of instrumental surveying-geodesic observations of the benchmarks position at station I of the Sokolovskiy open pit

Benchmark No	Y	X	Z
Results of measuring with electronic total station Leica TCA 1202			
Rp-I	1235, 494	5145,544	177,364
IE-6»	2496,423	4811,434	-25,762
Results of measuring with GPS receiver Leica 1200			
Rp-I	1235, 491	5145,546	177,359
IE-6»	2496,419	4811,437	-25,767

Based on the analysis of the results of studying the edge and dump masses of the Sokolovskiy open pit on September 24, 2010 there were the following conclusions:

- to use satellite systems GPS for inserting the transition points in the mode "fast statics" taking into consideration the developed methodology of reducing a satellite signal distortion in the ionosphere, the antenna phase center and the shaded effect.

Practical use of GPS System in Kazakhstan

Before the laying of profile lines the system of monitoring included 6 points in the western part of the pit wall in the location of the dam. On a ramp in the Southern part of the pit wall 3 points are established. Two points 220-1, 205-1 are installed on the northern pit wall. On the weakened sites of the open pit the places of detection of the cutter break and cracks reference points 200-1, 205-1, 220-1 were installed.

Besides above-mentioned factors, existence of large amount of snow and ice on safety berm has weaken impact on the stability of these pit walls. Melted snow saturates a massif in the zone of the residual soil and causes loss of rock strength properties. Previously mentioned ice formations melt for a long time until the end of spring. At inspection on the western pit wall the local rock fall was revealed on +200m level (Figure 9).

The condition of installation of the reference marks in the line of sight of Leica GeoMoS system was satisfied. For this purpose, were designed profile lines, which were imported in Surpac program, taking into account the direct visibility of points and operating crushing station. Obstacles for the surveying of reference points were noted and defined beforehand. The greatest difficulties were caused by the position of a crusher and conveyor line on southwest pit wall and also the position of the road on the top level of the southern pit wall.

Figure 9. Ice formations and accumulations of water on safety berm on the southern pit wall in the ramp area (April 2012) and cutter breaks on the western pit wall on the +200m level

As result of the work four profile lines consisting of prismatic reflectors were installed taking into account the current state and prospect of development of mining operations (Figure 10).

14 monitoring points were installed in two profile lines on the southern pit wall. In the western pit wall were also installed 2 profile lines with 14 monitoring points (8 points – line 3, 6 points – line 4). Prismatic reflectors for automatic surveying by GeoMoS system were fixed on all points.

Preliminary monitoring of reference points position was made by using bifrequency GPS Leica receiver in the stop-and-go mode. Measurements were carried out by two series at 10 and 11 of May, 2012. According to GNIP (ONTA)-02-262-02 – the instruction on development of fixed stations/control network and situation and relief surveying with application of global navigation satellite systems GLONASS and GPS the minimum quantity of satellites at measurement has to be not less than four. At realization of satellite measurements it is not recommended to use the satellites which eminence over the level is less than 15 degrees, otherwise the obtained data will be distorted considerably by influence of an atmospheric refraction.

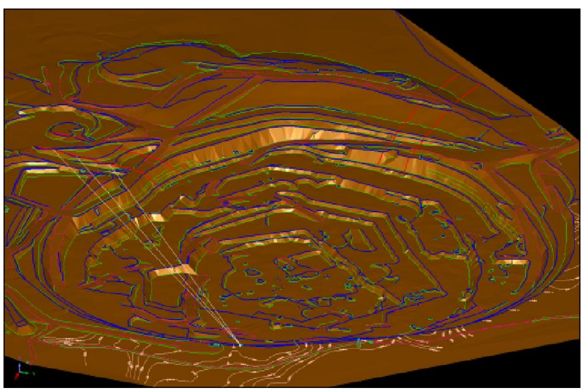

Figure 10. Plan of the open pit with an actual position of the profile lines

On the first and the second observational lines two surveying series were made. On the third and fourth line the first measurements were carried out for definition of an approximate position of the points. The second measurement was carried out on installed reference points. Results of comparison of measurements on lines 2-2 are shown in the table 6.

Table 6. Results of GPS measurement along the line 2

№	I measurement			II measurement			Measurement disparity		
	x	y	z	x	y	z	x	y	z
1	6868.640	7806.526	238.400	6868.640	7806.524	238.400	0.000	0.002	0.000
2	6900.537	7803.450	238.300	6900.531	7803.444	238.300	0.006	0.006	0.000
3	7031.093	7804.080	225.800	7031.096	7804.076	225.800	-0.003	0.004	0.000
4	7053.259	7804.463	216.900	7053.263	7804.458	216.900	-0.004	0.005	0.000
5	7142.340	7802.010	206.400	7142.339	7802.006	206.390	0.001	0.004	0.010
6	7173.476	7804.713	175.200	7173.473	7804.710	175.200	0.003	0.003	0.000

According to the results GPS measurements not always yield good results in the bottom levels of the open pit despite location of a base station in a distance less than 5km. The maximal deviation in the plan is less than 6 mm. Height difference amounts to 10мм. On the level +178m the height difference is 100mm. Large divergences on +178м level are bound to the errors of a satellite signal: shadow effect, effect of a multipath signal and small number of satellites [3, 4]. From the aforesaid it is necessary to draw a conclusion that GPS measurement which are carried out in the "stop and go" mode are not applicable for monitoring of straining processes on open pit. Statics surveying mode takes a lot of time and also cannot be applied on the bottom levels of the open pit because of the poor pass ability of satellite signals.

4. Conclusions

Using global positioning systems in Kazakhstan when observing open pit slopes displacements is not widely used currently. The studies carried out revealed a number of issues be solved for successful implementing GPS at other open pits. Research errors of GPS carried out in Technical University of Clausthal, Germany and Moscow State University of Geodesy and Cartography, Russia. A result of calculation errors of GPS for ionosphere and troposphere calculated opportune time high-precision measurements in Central Kazakhstan.

For the antenna GPS to reduce «multipath» errors for satellite signal attached metallic disk. Research in the "kinematics" showed that the use of this device can improve the measurement accuracy of 25%. When increasing the height of the antenna with a metal disk and without it accuracy is also reduced.

In the measurement in the "fast static" with metallic disk, the accuracy of measurement is increase of 15%.

Derived a formula acceptable distance from the slope to implement measurement in the "kinematics".

This methodology to reduce errors of distortion of the satellite signal, was successfully implemented in the open pits of Kazakhstan: Varvarinskiy, Vasilkovskiy and Sokolovskiy.

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